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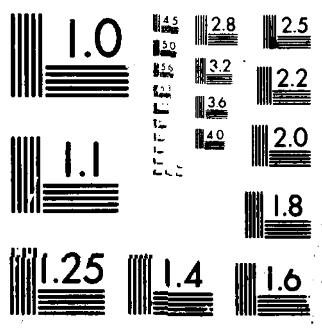

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FAA Integrated Noise Model Validation

Phase I: Analysis of Integrated Noise Model Calculations for Air Carrier Flyovers

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16. Abstract

The Federal Aviation Administration's Integrated Noise Model is a set of computer programs which is used to predict the noise impact of aircraft in the vicinity of an airport. Through use of extensive statistical analyses, this study investigates the accuracy and suitability of the noise model in calculating aircraft noise exposure by: (1) examining the agreement between the noise model in calculating single noise events and the actual measurement of those events, (2) assessing the sensitivity and controllability of the noise model to aircraft thrust assumptions, and (3) investigating noise curves used in calculating noise exposure by testing variables for significance in estimating noise and by comparing the shape of empirical noise curves with those already in the noise model. Data for the analysis were obtained from field observations of noise from air carrier flight operations over various noise monitoring sites near Washington National and Dulles International Airports.

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EXECUTIVE SUMMARY

INTRODUCTION AND BACKGROUND

The Department of Transportation/Federal Aviation Administration (FAA) Integrated Noise Model (INM) is a set of computer programs which are used to predict the noise impact of aircraft in the neighborhood of an airport. The purpose of the INM validation project is to determine the accuracy of the FAA Integrated Noise Model (Version I) by comparing INM noise exposure calculations with actual measured noise exposure levels. The current phase of the project centers upon statistical analyses of single events in which calculated and observed noise exposure levels from air carrier flight operations are compared. This comparison uses data from various noise monitoring sites around Washington National and Dulles International Airports.

The methodology employed in this analysis is a refinement of that initially presented in MTR-7913, "Analysis of Integrated Noise Model Calculations for Concorde Flyovers" (Reference 1). In that paper, statistical techniques were presented to quantify the noise characteristics of Concorde operations at Dulles International Airport. The same basic methodology together with certain extensions are now applied to representatives of the following types of aircraft: two and three engine narrow body jets, four engine narrow body jets, and wide body jets.

ISSUES IN THIS STUDY

Issue 1: Determining Agreement Between Calculations and Measurements

In this validation study, INM calculations for various aircraft are analyzed separately. Statistical methods are used to quantitatively check the agreement between calculations and measurements of noise exposure by using paired differences between the observed noise and the noise model calculation for the same flight condition. The paired difference is formed by using the measured noise exposure from a single aircraft flyover and comparing it with the calculated noise exposure resulting from using the measured slant-range distance, altitude, and velocity of the aircraft at its closest point of approach to the monitor site. The resulting statistic portrays the average difference in noise exposure from aircraft flyovers abeam a monitor site and the INM noise calculations for the same simulated flyovers.

Issue 2: Assessing Sensitivity to Noise Model Thrust Assumptions

The methodology for determining the INM's sensitivity to thrust involves using the noise-thrust mapping procedure developed in this study and the computed difference between the observed noise and the INM calculation from the aircraft's flight characteristic. The noise-thrust mapping procedure allows the translation of measured noise into equivalent thrust values. This translation is based on the assumptions that the noise model is functionally correct and that the difference between measured and calculated noise is primarily attributable to the assumed thrust profiles. This procedure enables the assessment of the innate controllability (amount of change in INM calculated noise values corresponding to the allowable range of thrust values for a particular aircraft type) of the thrust profiles in the INM data base to make calibrated adjustments.

Issue 3: Investigating Empirical Models for Noise Exposure

The third aspect of the comparison between the observed noise and INM calculations involves looking at the observed noise values to answer three questions: (1) Which of the observed variables associated with the noise event (measured noise for the aircraft flyover) is most highly correlated with that noise event? (2) What is the mathematical form of the variable used to describe the noise event relationship? (3) Using the "best" mathematical description of the noise event relationship, does the mathematical description agree with the noise curves used in INM calculations?

RESULTS AND CONCLUSION

Over 6000 single-event noise measurements (measured noise for an aircraft flyover abeam a monitor site) were taken and paired with calculations from the INM for statistical comparison. The observations were categorized by aircraft type, monitor site, and type of flight operation, i.e., departure or arrival. The events for each airport, for each aircraft type, and each flight operation were combined for grouped statistics. The aircraft types were then arranged in three groups: four engine narrow body aircraft, two/three engine narrow body aircraft, and wide body aircraft.

The results of three separate analyses of aircraft departures, and arrivals their noise measurements, and their comparison with analogous noise calculations by the FAA Integrated Noise Model are summarized in Tables 1 and 2. Based on these results as

TABLE 1

COMPARISON OF CONTROLLABILITY AND AGREEMENT FOR AIRCRAFT DEPARTURES (NEL OBSERVATIONS)

AIRCRAFT GROUP	AIRCRAFT TYPE	NEL DIFFERENCE BETWEEN OBSERVED NOISE AND INM CALCULATION (dB)[1]	THRUST PROFILES IN INM CAN BE CALIBRATED TO PRODUCE AGREEMENT[2]	AGREEMENT OF 95% CONFIDENCE BAND FOR OBSERVED NOISE WITH INM CLIMB NOISE CURVE[3]	
				AGREEMENT	RELATIVE POSITION
TWO AND THREE ENGINE NARROW BODY	DC-9	-3 to -2	YES	PARTIAL	LOW
	727	-2 to 0	YES	MOST	SLIGHTLY LOW
	737	-3 to -1	YES	PARTIAL	LOW
FOUR ENGINE NARROW BODY	707-120	5 to 6	NO[1]	NONE	HIGH
	707-320	5 to 7	NO	NONE	HIGH
	DC-8-55	2 to 5	NO	PARTIAL	HIGH
	DC-8-60	6 to 7	NO	NONE	HIGH
THREE AND FOUR ENGINE WIDE BODY	747	2 to 3	YES	PARTIAL	HIGH
	DC-10-10	3 to 4	NO	NONE	HIGH
	L-1011	4 to 5	NO	NONE	HIGH

[1] DULLES MONITOR SITES

[2] INM THRUST REQUIRED TO PRODUCE OBSERVED NOISE DURING CLIMB EXCEEDS MAXIMUM THRUST FOR TAKEOFF; INM NOISE CURVES MUST BE REDEFINED TO PRODUCE AGREEMENT

[3] NONE=NO AGREEMENT
PARTIAL=PARTIAL AGREEMENT
MOST=AGREEMENT IN MOST OF RANGE
HIGH=BAND ABOVE INM CURVE
LOW=BAND BELOW INM CURVE

TABLE 2

COMPARISON OF AGREEMENT FOR AIRCRAFT ARRIVALS
(NEL OBSERVATIONS)

AIRCRAFT GROUP	AIRCRAFT TYPE	NEL DIFFERENCE BETWEEN OBSERVED NOISE AND INM CALCULATION (dB)[1]	AGREEMENT OF 95% CONFIDENCE BAND FOR OBSERVED NOISE WITH INM APPROACH NOISE CURVES[2]	
			AGREEMENT	RELATIVE POSITION
TWO AND THREE ENGINE NARROW BODY	DC-9	1 to 2	--	--
	727	-3 to -2	PARTIAL	SLIGHTLY HIGH
	737	2 to 4	NONE	HIGH
FOUR ENGINE NARROW BODY	707-120	3 to 4	--	--
	707-320	5 to 6	--	--
	DC-8-55	2 to 4	NONE	HIGH
	DC-8-60	2 to 3	--	--
THREE AND FOUR ENGINE WIDE BODY	747	5 to 6	--	--
	DC-10-10	5 to 6	PARTIAL	HIGH
	L-1101	5 to 6	NONE	HIGH

[1] DULLES MONITOR SITES

[2] NONE = NO AGREEMENT
PARTIAL = PARTIAL AGREEMENT
MOST = AGREEMENT IN MOST OF RANGE
HIGH = BAND ABOVE INM CURVE
LOW = BAND BELOW INM CURVE
-- = NO STATISTICALLY VALID CURVE FOUND

well as others presented in this study, the following conclusions have been reached concerning the INM's performance in modeling air carrier operations at Dulles International and Washington National Airports.

1. The criterion for "non-agreement" is defined as the average of the paired differences (between actual observed noise from field measurements and calculations of analogous single noise events from the INM) being greater than three decibels (3 dB). The 3 dB criterion was selected as a compromise between setting a narrow margin for agreement, but still allowing a large enough margin to account for the wide range of measured noise values resulting from field observations of uncontrolled aircraft flight operations. Using this criterion, noise calculations derived from the use of the INM do not agree with actual observed noise values for four engine narrow body aircraft for departure operations, nor do they agree for most of the wide body aircraft types for departure operations. Because of the wide range of variability in measured values for arrival operations, the interpretation of the arrival data is difficult. (The confidence intervals for the average observed noise differences as well as the confidence band around the regression estimates are large.) Again, using the three decible criterion for only the observed differences, noise calculations derived from the use of the INM do not agree with actual observed noise values for wide body aircraft for arrival operations.

2. INM calculations of noise events can be changed or calibrated most easily by using two methods: adjusting thrust profiles, and adjusting noise curves. The method of adjusting thrust profiles alone does not have the inherent range (controllability) to allow the calibration necessary to make the results of the INM calculations for four engine narrow body aircraft, for example, comparable to actual measurements (i.e., even when the INM thrust is set for maximum takeoff thrust, the average observed noise is still greater than the resulting INM calculation. This situation is unreasonable since the maximum takeoff thrust is a limiting value, and when set at this maximum thrust value, an aircraft would theoretically produce the loudest possible noise value for that particular aircraft.) In order for the INM calculations to agree with the observed noise, the noise curves in the INM must be adjusted to reflect the actual measurements made in the field by redefining new noise curves.

RECOMMENDATIONS

The objective of the FAA Integrated Noise Model is to calculate the noise from aircraft operations in the vicinity of an airport (for an average day of the year in an operational environment).

The Noise Exposure Levels (NELs) used in the INM data base were derived mathematically from maximum sound level measurements with duration corrections obtained from Effective Perceived Noise Level (EPNL) measurements, and thus the NELs in the data base are in part theoretical. From these theoretical values, the noise versus distance curves now residing in the data base were obtained.

On the other hand, the empirical noise versus distance curves presented in this report are a reflection of an actual day of the year in an actual operational environment. These curves were derived from a cross-section sampling of aircraft operations for eight months of data acquisition. The observations are consistent and present a good means to satisfy the stated objective through fine-tuning the INM.

The following steps are recommended in order to improve the accuracy of the INM for aircraft types whose observed noise values do not agree with analogous INM calculations:

1. Adjust the noise curves in the INM for agreement by using empirical noise curves resulting from regression analyses of observed noise values. The noise curves should be adjusted to improve accuracy of noise calculations for takeoff and climb flight operations only, since the actual thrust values used for these operations are procedurally set to a relatively known and fixed value.

2. After adjustment of the noise curves, the noise-thrust mapping procedure described in this study should be used to fine tune or calibrate the thrust profiles for arrival operations. Certain assumptions will have to be made concerning what actual thrust value is being used abeam the various sites, as well as assumptions concerning the flight configuration (i.e., flap and gear extension). These assumptions are an integral part of the calibration process.

3. To insure that the calibration procedure is correct, a complete set of noise observations should be taken at two other airports and the statistical comparisons of observed noise versus INM calculations be repeated.

3. The results of the noise measurement comparisons based on data taken at Dulles International Airport are supported by those taken at Washington National Airport for two and three engine narrow body aircraft. (Four engine narrow body aircraft and wide body aircraft operations were observed only at Dulles Airport.)

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1. INTRODUCTION

The Department of Transportation/Federal Aviation Administration (FAA) Integrated Noise Model (INM) is a set of computer programs which are used to predict the noise impact of aircraft in the neighborhood of an airport. The purpose of the INM validation project is to determine the accuracy of the FAA Integrated Noise Model by comparing INM noise exposure calculations with actual measured noise exposure levels. The current phase of the project centers upon statistical analyses of single events in which calculated and observed noise exposure levels from air carrier flight operations are compared. This comparison uses data from various noise monitoring sites around Washington National and Dulles International Airports.

1.1 Background

The methodology employed in this analysis is a refinement of that initially presented in MTR-7913, "Analysis of Integrated Noise Model Calculations for Concorde Flyovers" (Reference 1). In that paper, statistical techniques were presented to quantify the noise characteristics of Concorde operations at Dulles International Airport. The same basic methodology together with certain extensions are now applied to representatives of the following types of aircraft: two and three engine narrow body jets, four engine narrow body jets, and wide body jets. It is assumed that the reader is familiar with aircraft noise descriptors and aircraft noise calculation models. A sophisticated knowledge of statistics is not required to understand the body of the paper; technical material relating to statistical techniques is presented in the appendices.

1.2 Areas of Investigation

A discussion of variability in observation and modeling presented in Reference 1 postulated that considerable variability might be anticipated between an INM calculation and an actual noise level observation, even when model inputs are carefully specified to accurately reflect the characteristics of the flyover. This contention was substantiated by the observed noise data for Concorde aircraft.

No aircraft noise model can be expected to predict accurately the noise level of an individual event. A valid model, however, will correctly determine the average noise level of a large number of similar flyovers. This notion of correctly determining the average noise level conceptually defines "validity." The following section enumerates the techniques which were

employed in the current study to put this notion on a quantitative basis. These techniques also examine the characteristics of the relationship between the observed noise values and the INM calculations. The areas of investigation are those concerning agreement, thrust sensitivity and noise curves.

1.2.1 Determining Agreement Between Calculations and Measurements

The first and most important aspect of the comparison between the observed noise and INM calculations is the ability of the model to portray the noise environment. In this study, INM calculations for various aircraft types are analyzed separately. This approach is taken because the overall accuracy of the INM is dependent on the accuracy of its calculations for each of the individual traffic mix entries presented to it as an input. The accuracy of the cumulative noise metric is bounded by the accuracy of the individual aircraft type entry. For example, if the noise exposure from each aircraft contributing to the total aircraft noise at a point is accurate to within 1 dB, the overall cumulative energy noise metric will also be accurate to within 1 dB, as a worst case.

1.2.2 Assessing Sensitivity to Thrust Assumptions

The second aspect of the comparison between the observed noise and INM calculations involves the sensitivity of the INM to assumed aircraft thrust profiles in the INM data base. The assumed thrust for an INM calculation of a noise event is important because it cannot be measured experimentally, but nevertheless must be estimated in order to perform the noise calculation. The actual thrust for an observed aircraft event may be different from the postulated thrust because of differences in individual pilot thrust management procedures or techniques, or because of inaccurate assumptions concerning the aircraft's flight configuration (i.e., gear and flap positions).

1.2.3 Investigating Empirical Models for Noise Exposure

The third aspect of the comparison between the observed noise and INM calculations involves looking at the observed noise values to answer three questions: (1) Which of the observed variables associated with the noise event (measured noise for the aircraft flyover) is most highly correlated with that noise event? (2) What is the mathematical form of the variable used to describe the noise event relationship? (3) Using the "best" mathematical model of the noise event relationship, does the mathematical description agree with the noise curves used in INM calculations?

1.3 Variation in Noise Observations

A characteristic of field observations involving uncontrolled aircraft flight operations is that observations of aircraft noise levels will inevitably exhibit a degree of variability. In tests conducted by NASA Wallops Flight Center, significant variation was observed among flyover noise levels for a single aircraft, despite tightly controlled pilotage procedures and essentially constant environmental conditions (References 2, 3). It can be expected that an even greater variability will be observed among operations of commercial aircraft using standard approach and departure procedures at public airports, yet it is from such observations that the data to be used in the INM validation is derived.

Uncontrolled field observations may also be expected to exhibit further variability when considered in relation to INM calculations. As Table 1-1 illustrates, the model is a greatly simplified representation of the factors affecting aircraft noise. Implicitly, the model assumes that the factors which are not modeled will "average out" in the long run. One follow-on goal of the INM validation project is to determine whether this assumption is justified.

The primary factors governing noise generation at the source are the aircraft type, engine type, and thrust. The thrust depends on the flight path, on how the pilot makes thrust corrections to correct his flight path (pilotage), and on aircraft configuration (flap settings and landing gear). Additional factors at the source include the effect of engine shielding by the airplane fuselage, variations in noise exposure values in a "lobe" pattern around the engine centerline (directivity), and frequency shifts because of velocity vector orientation (doppler effect).

Propagation effects include the relative distance between the source and receiver (spherical divergence), atmospheric attenuation (which varies as a function of the humidity, temperature, barometric pressure, and wind), and atmospheric turbulence involving temperature gradients and other atmospheric heterogeneities.

Receiver effects include ground attentuation, ground surface reflections and additional attentuation because of ground cover or intervening structures between the source and receiver.

TABLE 1-1

SOURCES OF VARIABILITY IN OBSERVATION AND MODELING

EFFECT	REAL WORLD	FAA INTEGRATED NOISE MODEL
SOURCE	AIRCRAFT TYPE ENGINE TYPE PILOTAGE CONFIGURATION SHIELDING DIRECTIVITY DOPPLER EFFECT THRUST	AIRCRAFT TYPE TAKEOFF/LANDING PROFILES (LINEAR) PRESSURE-TEMPERATURE CORRECTION FOR TAKEOFF SHIELDING
PROPAGATION	SPHERICAL DIVERGENCE ATMOSPHERIC ATTENUATION WEATHER CONDITIONS ATMOSPHERIC TURBULENCE	NOISE VS. DISTANCE TABLE
RECEIVER	GROUND ATTENUATION REFLECTIONS GROUND COVER/STRUCTURES	GROUND ATTENUATION

The INM makes certain simplifications to the real world effects in modeling aircraft noise. The aircraft type and engine type categories are combined. The pilotage variability is not accounted for; nominal thrust values for different flight regimes were drawn from manufacturer's data. There are temperature and pressure corrections made only to the takeoff profile. The landing gear/flap configuration is divided into takeoff or landing configuration only. Shielding and directivity effects are combined. There is no correction for the doppler effect. Spherical divergence and atmospheric attenuation are modeled by a noise versus distance table. There is no correction for atmospheric turbulence, reflections or ground cover.

Figures 1-1 and 1-2 show an additional area of variability: variability in the shape of the aircraft's noise-time history. These examples of histories of aircraft noise versus time are taken within the same hour over the Old Town monitor site at National Airport (DCA). Whereas the shape of noise time history for departures are more regular in that they increase in noise to a recognizable peak and then decrease, the time histories for arrivals are much more irregular. The designation "MAX" represents the maximum sound level, in decibels, for the particular noise-time history. The abbreviation "NEL" stands for Noise Exposure Level, which is the level of sound accumulated during a given event. More specifically, NEL, in decibels, is the level of the time-integrated A-weighted squared sound pressure for a given event.

The time histories for departures have a distinct peak which occurs near the midpoint of the time during which the noise value is above 70 dB(A). Seventy dB(A) is the threshold value of the sound level used at the Noise Monitor Facility to distinguish between aircraft noise events and ambient noise. The time histories for the arrivals in some cases have distinct peaks near the midpoint similar to those for departures; however, there are also examples of histories in which that is not the case, such as the bottom three graphs in Figure 1-2. The shape of these curves are more flat and in some cases the peak value does not occur near the midpoint of time during which the noise exceeds 70 dB(A). In some cases, the noise time history is nearly cyclical in nature.

In the foregoing discussion, the variation in the shape of the time histories for arrivals is much more substantial than those for departures. These inconsistencies are reflected in results of the analysis. Statistically, much less can be said concerning

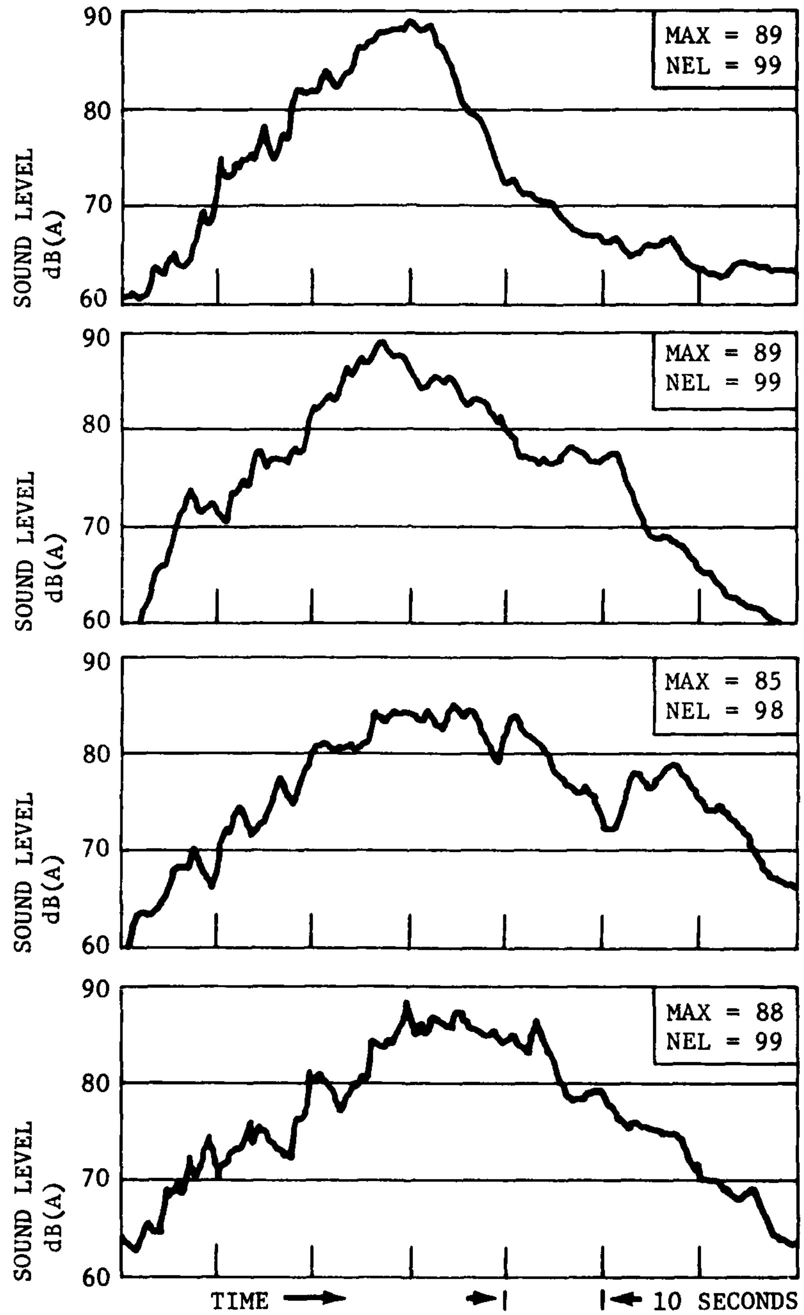


FIGURE 1-1
REPRESENTATIVE NOISE-TIME HISTORIES FOR AIRCRAFT DEPARTURES OVER OLD TOWN (DCA)

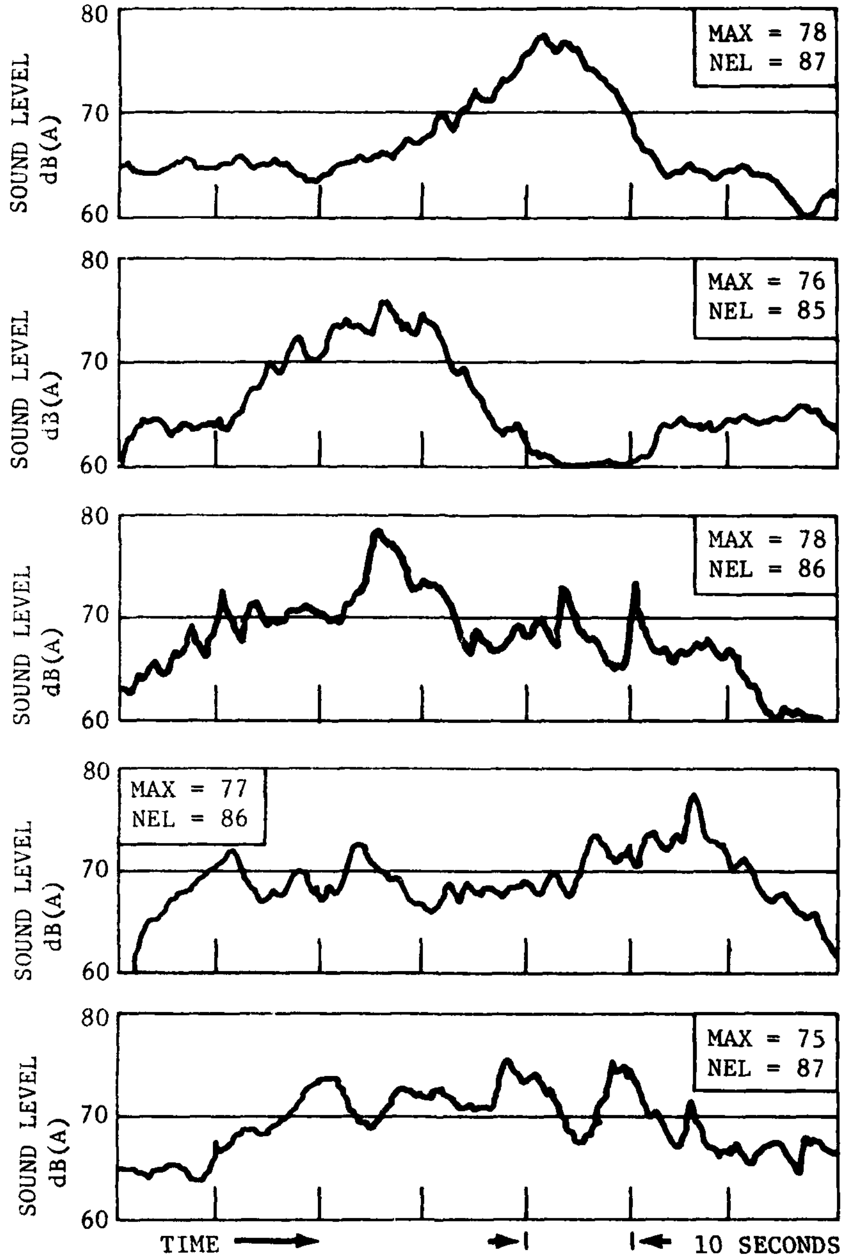


FIGURE 1-2
REPRESENTATIVE NOISE-TIME HISTORIES FOR AIRCRAFT ARRIVALS OVER OLD TOWN (DCA)

noise observations for arrivals than departures because the time integration process for NEL values tends to mask or average-out specific sound level characteristics of a particular aircraft approach.

Figures 1-3 through 1-6 show flight patterns of typical north and south operations at Dulles and National Airports (these figures are direct extracts from Reference 4). There are a variety of ground tracks abeam the various sites depicted on these airport maps. This graphically illustrates the fact that the observations used in this study are obtained under a variety of flight conditions. In addition to the variation in flight conditions, meteorological conditions varied considerably from May 1978 to January 1979, the dates during which the noise exposure levels were recorded. Consequently, one can expect a certain amount of variation in noise measurements even under the same nominal flight conditions.

1.4 FAA Integrated Noise Model Computer Program

The Department of Transportation/Federal Aviation Administration (FAA) Integrated Noise Model (INM) contains computer programs which can be used to estimate the noise impacts of aircraft in the neighborhood of an airport (Reference 5). The model estimates the noise impacts of aircraft operations using the following metrics:

Noise Exposure Forecast (NEF) -- An energy summation of the noise from a series of events, expressed in Effective Perceived Noise Level, weighted for a difference between daytime and nighttime noise exposure, and adjusted with an arbitrary constant.

Equivalent Sound Level (L_{eq}) -- The level of a constant sound, which in 24-hour time period has the same sound energy as does a time-varying A-weighted sound level.

Day-Night Average Sound Level (Ldn) -- The 24-hour period A-weighted equivalent sound level, which has a 10 dB penalty applied to nighttime levels (2200-0700 Local Time).

Community Noise Equivalent Level (CNEL) -- The 24-hour period A-weighted equivalent sound level, which has a 5 dB penalty applied to evening levels (1900-2200), and a 10 dB penalty applied to nighttime levels (2200-0700).

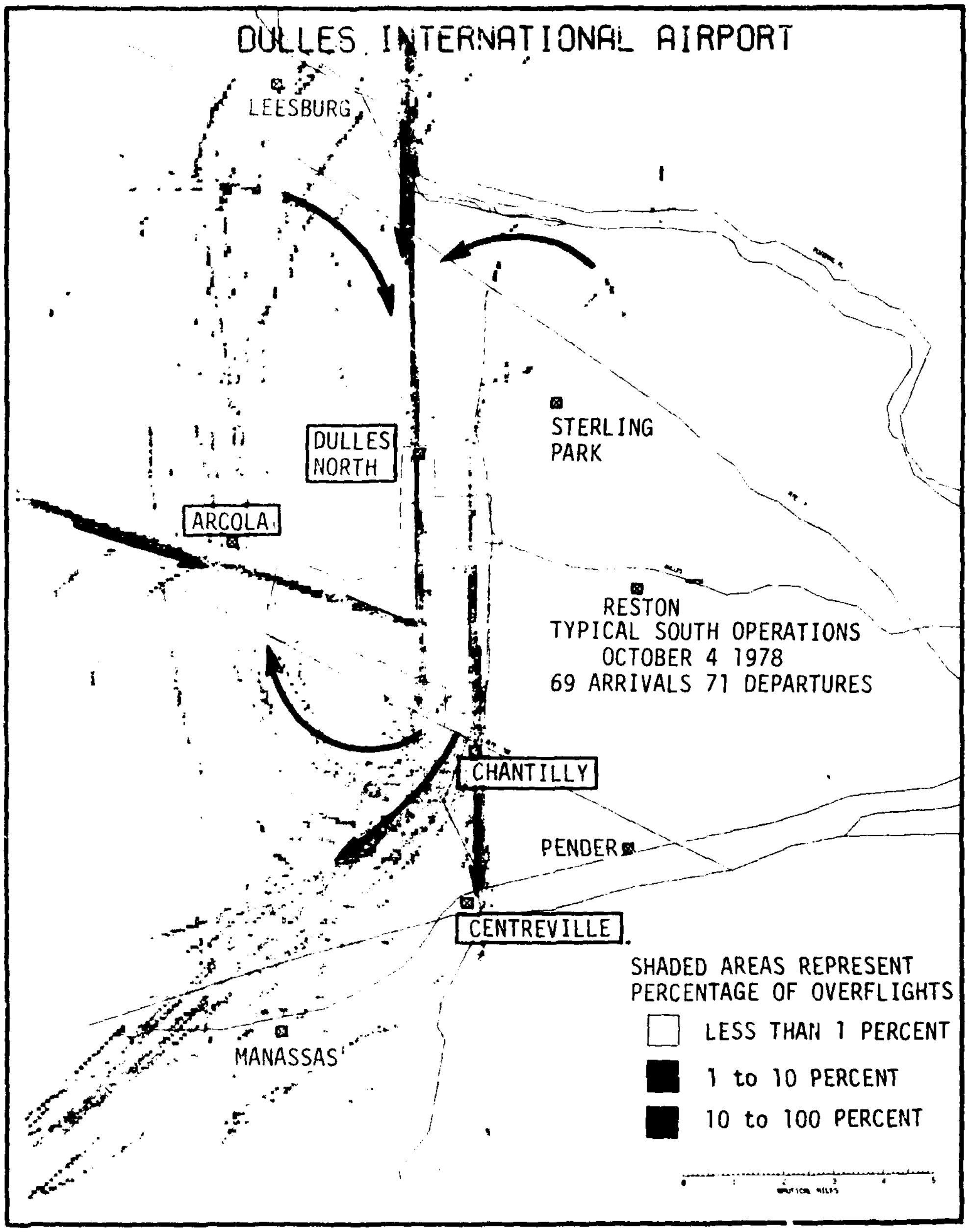


FIGURE 1-3
DULLES INTERNATIONAL AIRPORT'S MONITOR SITES
WITH TYPICAL SOUTH OPERATIONS

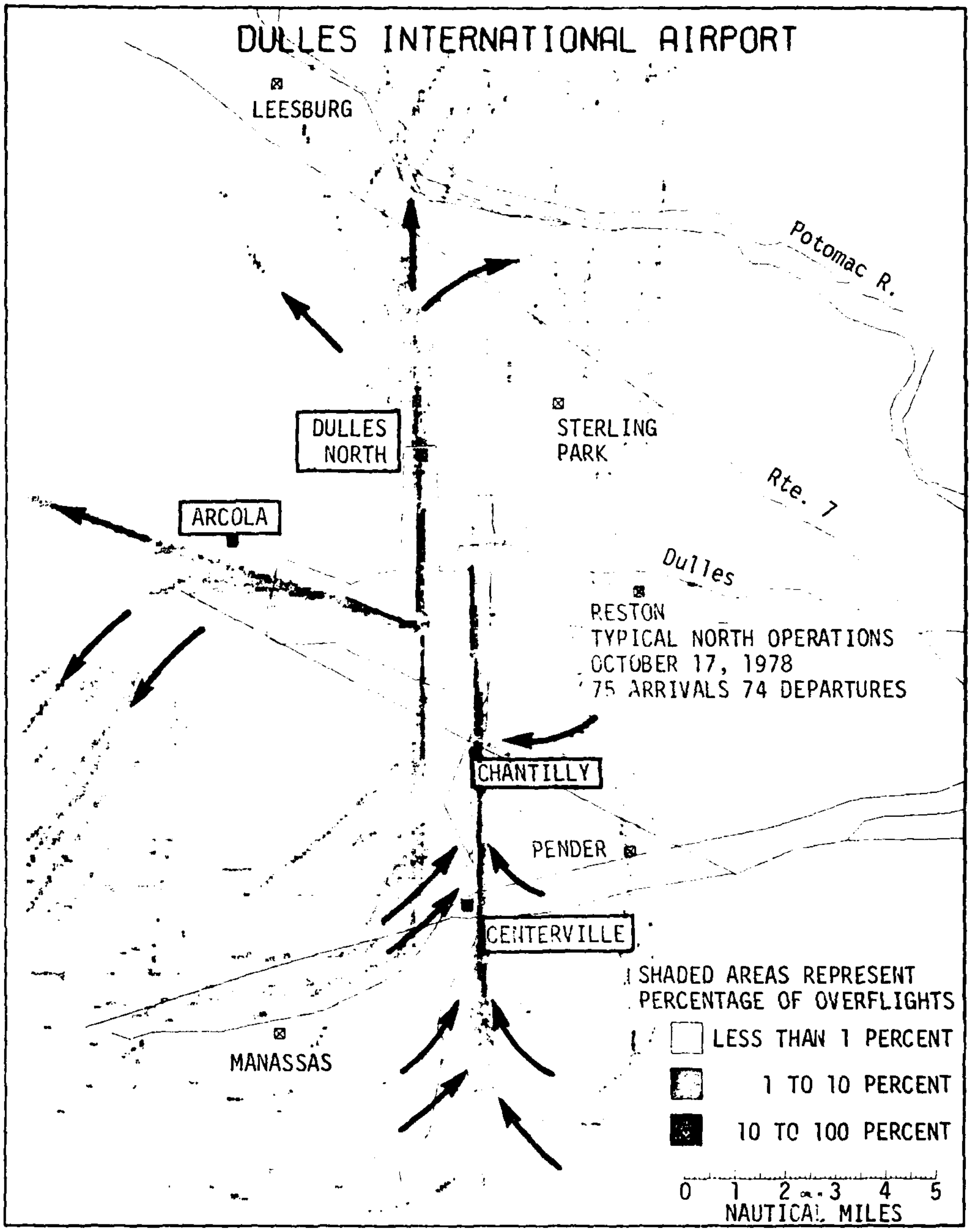


FIGURE 1-4
DULLES INTERNATIONAL AIRPORT'S MONITOR SITES WITH TYPICAL NORTH OPERATIONS

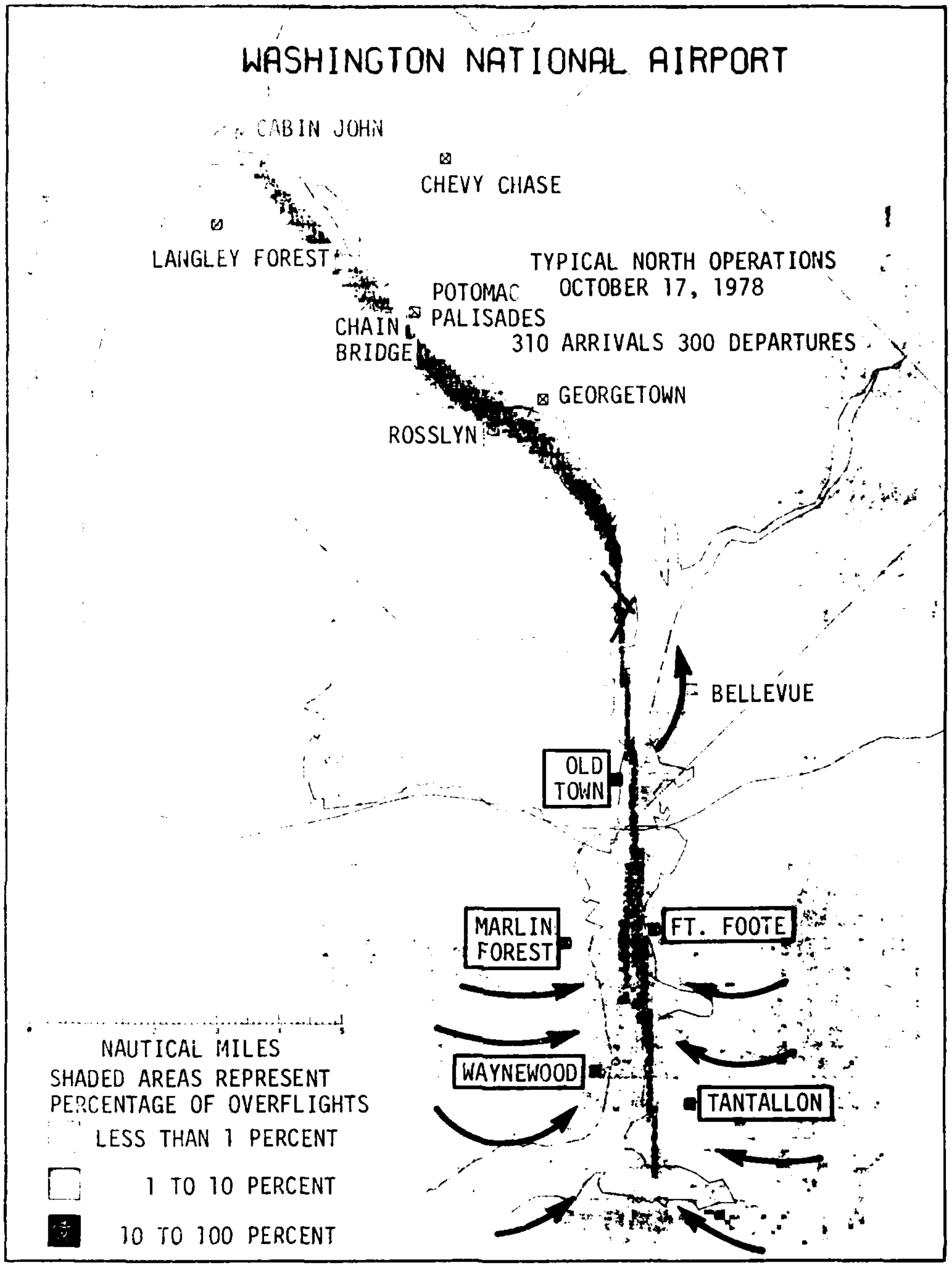


FIGURE 1-5
WASHINGTON NATIONAL AIRPORT'S MONITOR SITES WITH TYPICAL NORTH OPERATIONS

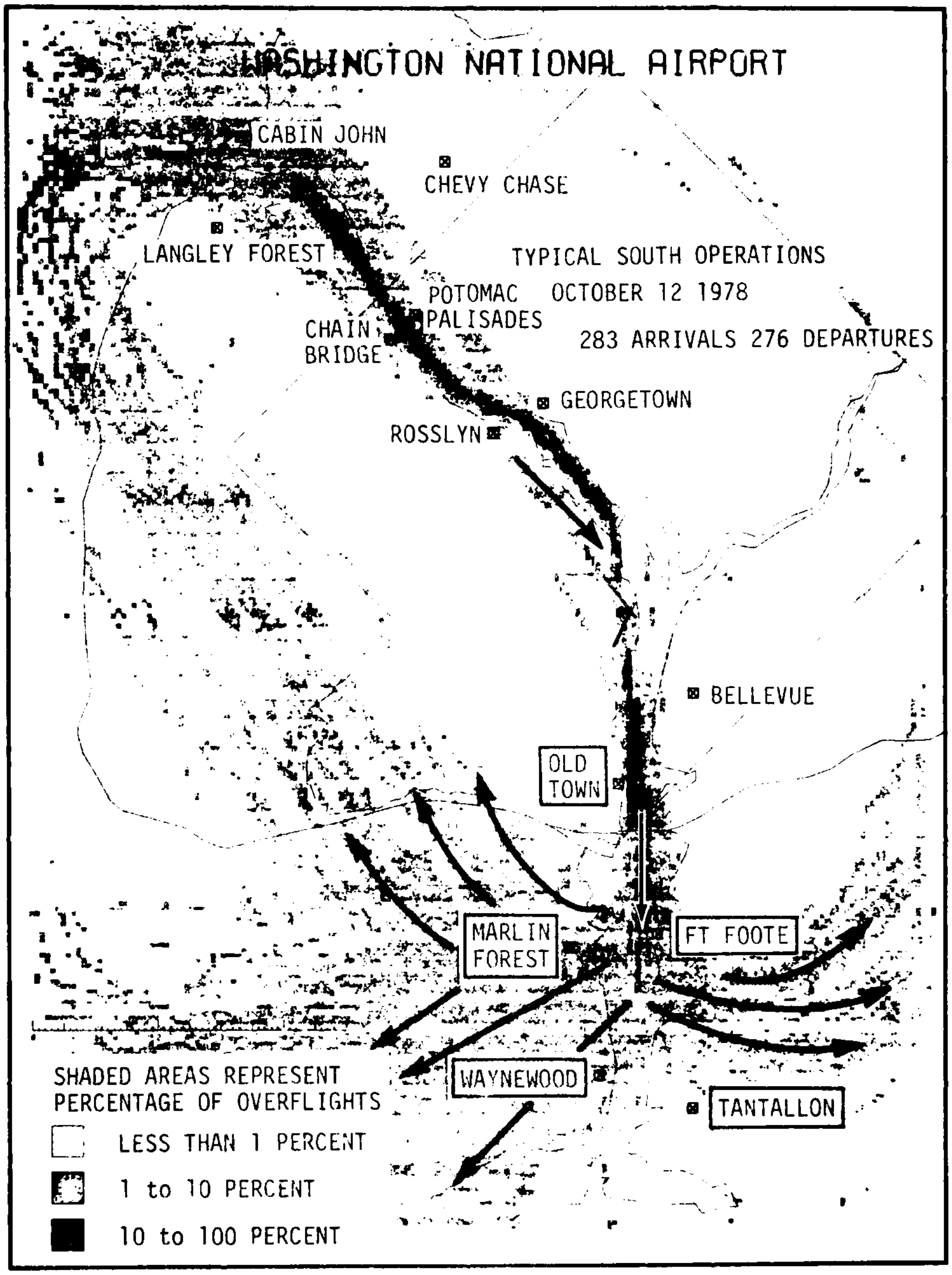


FIGURE 1-6
WASHINGTON NATIONAL AIRPORT'S MONITOR SITES WITH TYPICAL SOUTH OPERATIONS

Time of exposure above a threshold of A-weighted sound level (TA)--the time duration, in minutes, for which the A-weighted sound level at a measurement location is above a specified threshold.

The INM computer programs calculate the values of these metrics for selected points on the ground or in terms of contours of equal noise exposure.

The user of the INM provides the program with a description of the runways, ground tracks, aircraft types, operations and track utilization, approach profiles and takeoff restrictions. In this analysis, however, only single noise events (NEL observations) are considered. The ground track is defined by a straight line in the vicinity of a monitor site. Only one operation, either takeoff or landing, is assigned to the ground track. The values of the various noise metrics are calculated for the positions of the monitor sites relative to the ground track.

2. METHODOLOGY

This study investigates three areas to validate the accuracy of the FAA Integrated Noise Model (INM) in calculating aircraft noise exposure. These are (1) determining the agreement between the noise model in calculating single noise events and the measurement of those events, (2) assessing the sensitivity and controllability of the noise model to thrust assumptions, and (3) investigating noise curves used in calculating noise metrics by using regression models from empirical noise data.

2.1 Determining Agreement Between Calculations and Measurements

In this validation study, INM calculations for various aircraft are analyzed separately. Statistical methods are used to quantitatively check the agreement between calculations and measurements of noise exposure by using paired differences between the observed noise and the noise model calculation for the same flight condition. The paired difference is formed by using the measured noise exposure from a single aircraft flyover and comparing it with the calculated noise exposure resulting from using the measured slant-range distance, altitude, and velocity of the aircraft at its closest point of approach to the monitor site. The resulting statistic portrays the average difference in noise exposure from aircraft flyovers abeam a monitor site and the INM calculations for the same simulated flyovers. The observed noise measurements, when not corrected for distance, are usually not normally distributed, and thus, standard statistical techniques cannot be used to find the mean of the observed noise measurements. The method of paired differences, on the other hand, does make corrections for slantrange distance as well as for altitude and velocity. The paired differences are more normally distributed which allows employment of standard statistical techniques for determining the confidence interval for the mean difference between the measurement and calculation. The basis for the selection of this method is documented in Reference 1.

The noise metric used for the statistical comparison is the Noise Exposure Level (NEL). The NEL metric is the basic single event unit used for Equivalent Sound Level (L_{eq}), Day-Night Average Sound Level (Ldn) and Community Noise Equivalent Level (CNEL). Effective Perceived Noise Level (EPNL) and Time Above Threshold will be considered in a document to be published at a later date.

The analysis is performed in three stages: data collection, INM calculations and statistical comparison. The methodology is diagrammed in Figure 2-1.

2.1.1 Data Collection

Noise level observations for this study were obtained through the FAA's Metropolitan Washington Airports Noise Monitoring System (NMS). The NMS consists of a central computer complex, which is connected to a network of remote monitoring sites (RMSs) located in communities near Washington National and Dulles International Airports. The function of the system is to provide accurate data on aircraft noise in the communities surrounding the airports, to identify the aircraft responsible for specific noise events (by airline flight number and aircraft type), and to determine the flight paths of those aircraft.

Noise levels recorded by the RMSs are transmitted to a central computer system at Dulles. The computer keeps a record of each noise event for later source identification and analysis. Aircraft noise sources are identified by aircraft type and flight number, and flight paths are determined, by means of data from the Automated Radar Terminal System-III (ARTS-III) air traffic control computer system. This data is used to compute the time of closest point of approach (CPA) and associated flight characteristics such as distance, altitude, velocity and vertical velocity.

Nine monitor sites were used in the INM validation study, four of them located near Dulles International Airport and five located near Washington National Airport. These sites were selected because of their proximity to the airport and for their position near the centerline of departure or arrival ground tracks. The distances from the landing threshold and the primary runway used for departures or arrivals are listed for the nine monitor sites in Table 2-1.

The noise observations, together with data resulting from the aircraft flight paths and flight plans, were correlated or matched with each other as to aircraft type and then filtered. Conditions to accept the data for further processing were added to help eliminate questionable data by accepting only that data which were most likely to be an aircraft on arrival or departure flight path. These conditions were necessary because data concerning the actual flight path was unavailable and only those flight characteristics at the aircraft's closest point of approach to the monitor site was entered into the data base. These filtering conditions were:

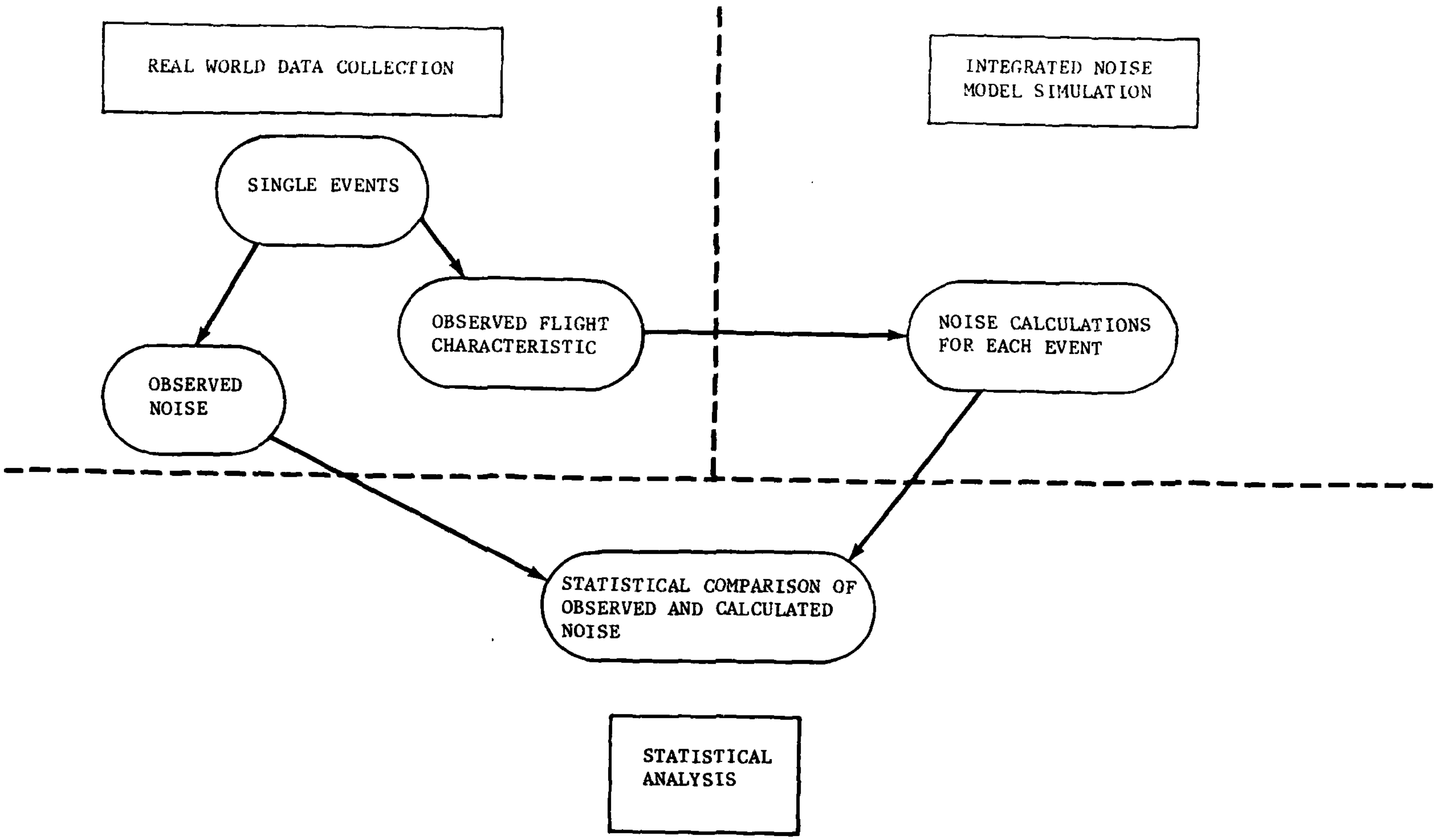


FIGURE 2-1
VALIDATION METHODOLOGY

TABLE 2-1

MONITOR SITES USED IN INM VALIDATION

AIRPORT	MONITOR SITE NAME	PRIMARY RUNWAY USED	DISTANCE FROM LANDING THRESHOLD (nmi)
DULLES INTERNATIONAL	DULLES NORTH	01L,19R	1.2
	CHANTILLY	01R,19L	1.9
	ARCOLA	12,30	2.6
	CENTERVILLE	01R,19L	4.9
WASHINGTON NATIONAL	OLD TOWN	18,36	2.2
	FT. FOOTE	18,36	4.6
	MARLIN FOREST	18,36	4.8
	WAYNEWOOD	18,36	6.9
	TANTALLON	18,36	7.3

1. The distance of the aircraft to the monitor site at the point of closest approach must be less than 10,000 feet. (This condition eliminates operations which have low noise values close to the ambient level.).

2. The duration of the noise event during which the noise exceeds 70 dB(A) must be greater than 6 seconds. (This condition helps eliminate non-aircraft noise events).

3. The absolute value of the vertical velocity must be greater than 200 feet per minute. (This condition eliminates level-altitude flyovers such as those on down-wind leg.).

4. The altitudes for departures must be greater than 1500 feet above ground level. (This puts departures, from a procedural standpoint, in the cutback or climb thrust region).

In this analysis, in addition to engine thrust, two other variables could not be quantified. These are aircraft weight and status of the aircraft engine nacelle/acoustic treatment. The INM has different flight performance profiles for particular aircraft types according to the weight of the aircraft. These profiles model thrust, altitude, and velocity as the aircraft proceeds along its flight path. For a particular position along this flight path, however, the INM noise calculation with reference to a particular point on the ground is independent of the aircraft weight. The actual altitude and velocity calculated from the aircraft's radar track are being used in the INM noise calculation. Theoretically, the aggregation of noise events without regard to weight should not affect the results of the comparison.

The INM also has different noise curves for particular aircraft types depending on whether or not it has engine nacelle/acoustic treatment. Statistically, the two types of engines would cause a bimodal distribution of noise measurements at the various noise monitor sites. The bimodal distribution would be especially noticeable during arrival operations, resulting from aircraft with the acoustic treatment measuring quieter than aircraft with standard engines. If the quieter aircraft with acoustic treatment were to be removed from a sample containing both types of engines, the average noise level of the sample containing aircraft with only standard engines would be higher. The actual effect of both the aircraft engine nacelle/acoustic treatment and aircraft weight on noise exposure levels is under current investigation.

2.1.2 INM Noise Exposure Calculation

The noise model includes in its data bases descriptions of flight profiles which define the flight characteristics along the ground track and noise versus thrust and distance curves for different aircraft types. Examples from this data base together with the mechanics of the noise exposure calculation are given in Appendix A.

Because the actual thrust setting data were not available, assumed thrust levels had to be input to the model before the noise model could compute the noise exposure. (The sensitivity of the noise exposure calculation to the thrust estimate is investigated in Section 2.2 of this study.) The thrust assumptions are complicated by the fact that Dulles and National Airports have different operational procedures for takeoff.

Prior to October 17, 1978, aircraft departing from Dulles were instructed to use the standard takeoff procedure advocated by the Air Transport Association. This procedure dictated that aircraft use takeoff power until reaching 1500 feet above the ground and then reducing power to maximum continuous limiting thrust for climb to en route altitude. Aircraft departures from National Airport, on the other hand, were instructed to use a modified climb procedure. This procedure dictated using takeoff thrust to an altitude of 1500 feet above ground level and then reducing power to a thrust setting which will maintain 500 feet per minute climb rate under hot day conditions. On October 17, 1978, the FAA issued an advisory circular (Reference 6) which changed the altitude at which takeoff power is reduced from 1500 feet to 1000 feet.

For departures from Dulles and National Airports the thrust assumptions were derived from the flight profiles included in the INM computer package. For departures from National Airport, in particular, the thrust value was calculated by the INM computer package so that the aircraft maintained a 500 feet per minute climb rate.

For arrivals the thrust assumption was obtained from an example in the "INM User's Guide" (Reference 5) which gives the approach thrust as a function of distance from runway threshold. For the Dulles North, Chantilly, Arcola, and Old Town monitor sites, the thrust was assumed that for an approach using a 3^{o} glide slope and landing flap extension. For all the other sites, the thrust was assumed that for maintaining level flight with an approach flap extension.

The distance from the aircraft to the Remote Monitor Station, altitude of the aircraft and velocity of the aircraft are all direct inputs to the INM calculation of noise exposure. The aircraft type, flight operation determination (takeoff or landing) and distance from the monitor site to the runway are used to determine the thrust estimate which in turn is used to determine the noise curve relating noise versus distance from the aircraft to the monitor site. Once the noise exposure has been calculated for the particular flight condition, the observed and calculated noise levels are then compared.

2.1.3 Statistical Comparison

The statistical comparison presented analyzes the distribution of the differences between observed noise levels and corresponding noise model calculations. The measured noise levels are not normalized or adjusted for any variable. Since the INM has algorithms which incorporate distance, altitude and velocity in its computation of the noise exposure level, the INM calculation for a given noise event accounts for these variables. The mean and standard deviation of the sample containing the paired noise values was then used to determine the confidence interval for the average difference between the measured and calculated values.

Examples of departure and arrival noise measurements and calculations are shown in Figures 2-2 and 2-3. In the upper left scatterplots, each observed noise event has a corresponding INM calculation. Each of the paired differences (observed noise minus INM calculation) is then plotted in the lower left scatterplot.

The probability density estimates for the observed noise and the differences are plotted on the right. The method by which these densities were derived as well as the calculation of the Kolmogorov-Smirnov statistic ("K-S STAT") are described in Reference 1. The Kolmogorov-Smirnov statistic tells whether or not the sample could have come from a normal distribution. If the statistic is less than 1.05, the sample can be said to be normally distributed. If the statistic is greater than 1.05, it is highly unlikely that the sample is normally distributed. As seen in Figures 2-2 and 2-3, correcting the observed noise values for distance produces a distribution which is more normal looking.

The 95% confidence interval for the mean of the difference between the observed noise and INM calculation is shown in the lower right density estimate as a horizontal line joining two vertical lines as in a sidewise "I".

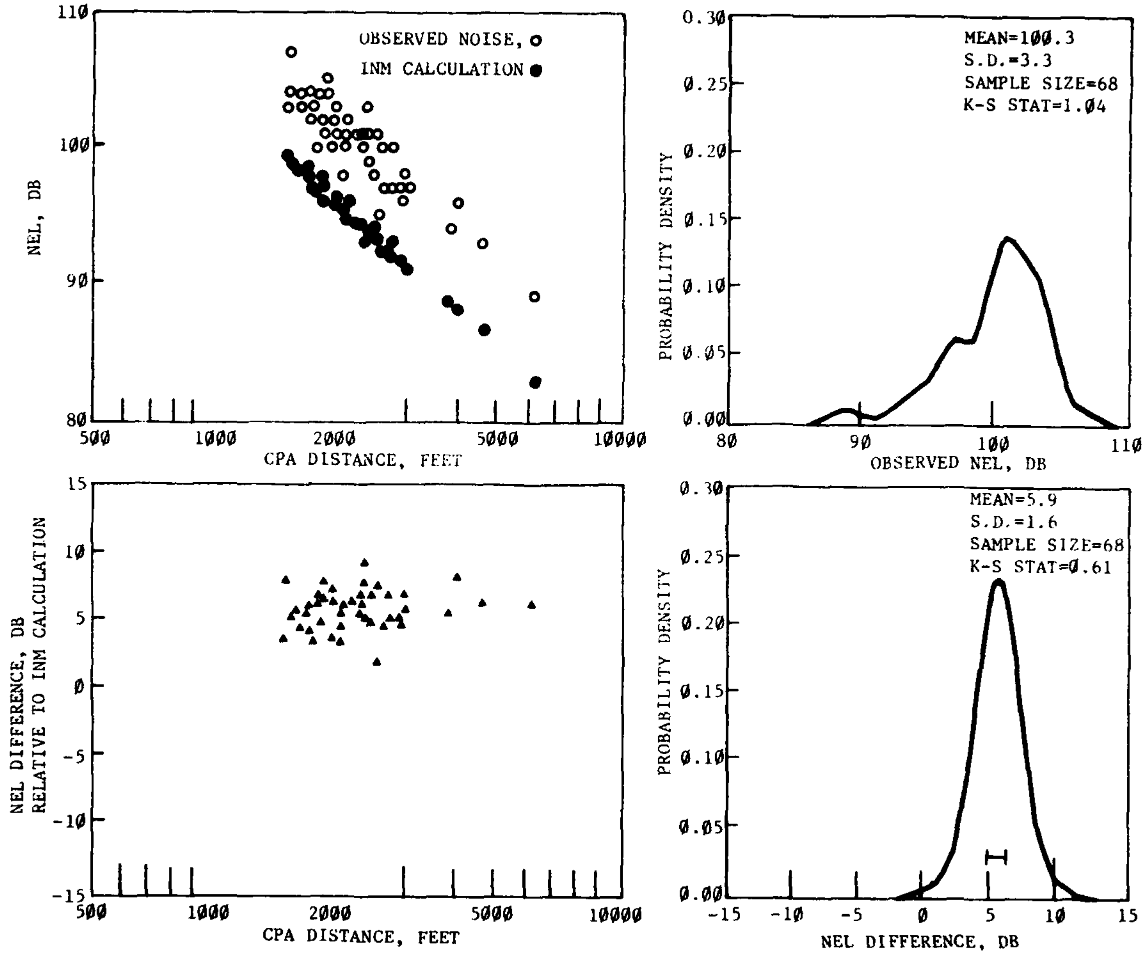


FIGURE 2-2
DC-8-60 DEPARTURES OVER CHANTILLY (IAD)
DATES: MAY 5, 1978 - NOVEMBER 6, 1978

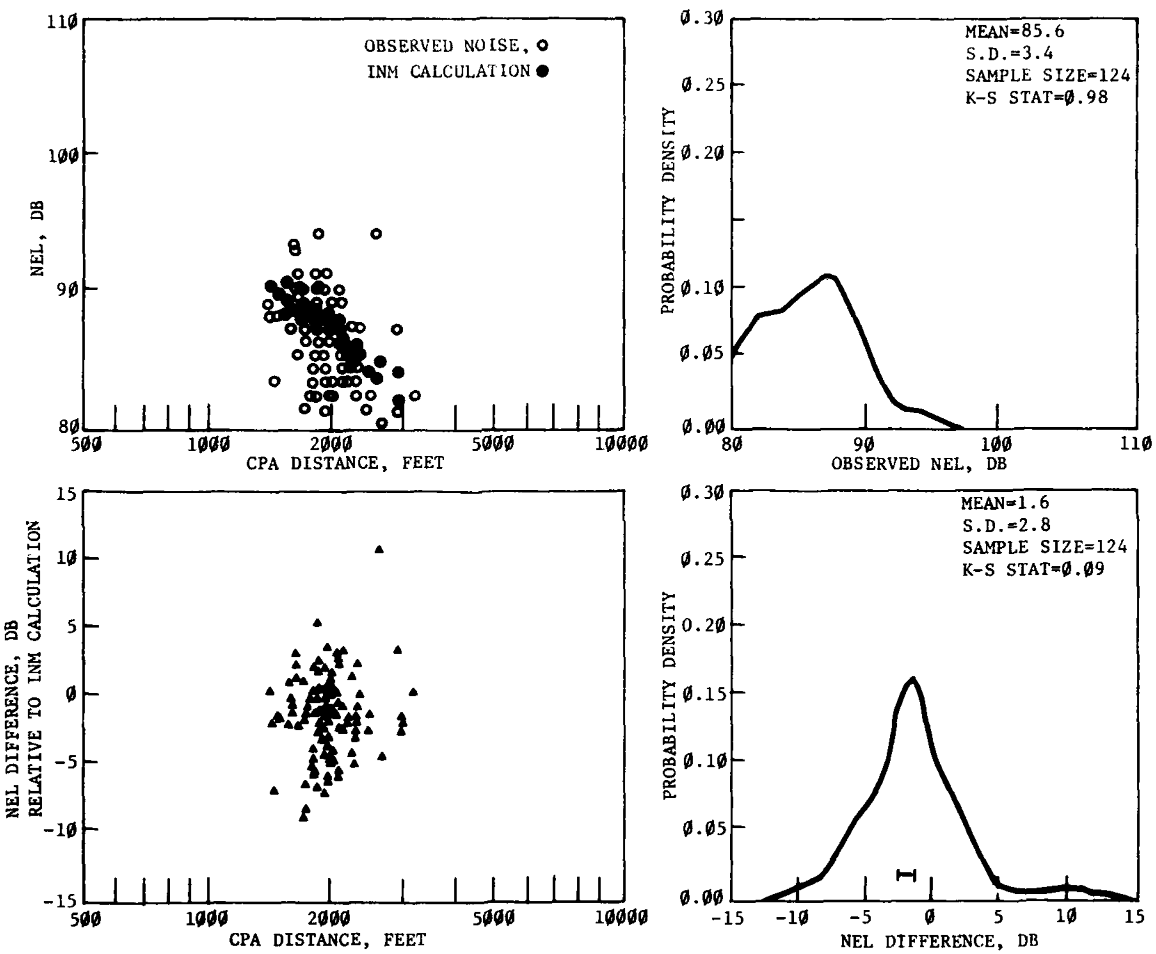


FIGURE 2-3
DC-9 ARRIVALS OVER FT. FOOTE (DCA)
DATES: APRIL 26, 1978 - OCTOBER 17, 1978

2.2 Assessing Sensitivity to Thrust Assumptions

A strong mathematical relationship exists between the Noise Exposure Level and the slant-range distance at closest point of approach. The noise level is also strongly related to the thrust level. The thrust level, unfortunately, cannot be measured; however, the thrust level must be estimated in order to obtain a noise model calculation.

One problem of using noise data from Dulles and National Airports is that the aircraft use different thrust profiles for departures. Since thrust levels cannot be measured directly, this means that the absolute differences between the observed noise and INM calculations may be caused in part by different thrust assumptions, namely, the assumed thrust for the INM calculation can be a different thrust level from that actually being used. Since thrust assumptions can influence the results of the comparison markedly, a method by which the comparisons could be made to a common datum had to be found. This method is the noise-thrust mapping procedure which translates the measured noise into equivalent thrust values. This translation is based on the premise that the noise model is functionally correct, and that the difference between measured and calculated noise is primarily attributable to the assumed thrust profile. The INM calculation is corrected for slant-range distance, velocity and altitude, leaving thrust as the only primary variable which is unaccounted for. Essentially, this method uses the INM as a yardstick to transpose from the noise regime to the thrust regime and back again.

Another problem arises from some of the monitor sites being situated near the point at which the power is to be reduced from takeoff power to a cutback power for climb. An example is the Old Town monitor site at National Airport. If an aircraft were actually still using the takeoff power setting but a cutback thrust setting was assumed for the INM calculation, the difference between the two would be unusually large. However, using the noise-thrust mapping procedure to obtain an estimate of the thrust used by the aircraft abeam the monitor site, errors in the INM calculation because of an inaccurate thrust assumption can be found easily.

The problem of developing useful thrust assumptions is compounded for arrival aircraft. Included in a ten nautical mile approach path are differing flight conditions such as whether the aircraft is in level flight or descending, whether or not the landing gear is extended, and the degree of extension of the

landing flaps. Each combination of these flight conditions requires a different thrust setting to maintain a stabilized flight path. For a typical approach profile, the INM has five different thrust settings. By using the noise-thrust mapping procedure, the relative location of these thrust settings are found easily.

Another major advantage of using the noise-thrust mapping procedure is that it enables an assessment of the innate controllability of the thrust curves in the INM data base to make calibrated adjustments. If the estimated thrust resulting from the noise thrust mapping procedure is greater than the takeoff thrust, for example, then no adjustment is possible and the thrust curves may have to be redefined.

The methodology for determining the INM's sensitivity to thrust involves using the noise-thrust mapping procedure and the computed difference between the observed noise and the INM calculation of noise from the aircraft's flight characteristic.

2.2.1 Noise-Thrust Mapping Procedure

The noise-thrust mapping procedure begins with the thrust assumption used to compute the difference between observed noise and INM calculation, as shown in Figure 2-4. Using a linear interpolation scheme based on the log average of the distances at closest point of approach (CPA) for a particular sample, the nominal noise value is calculated from the thrust curve for the nominal thrust (initial estimate) and average distance as illustrated in Figure 2-5. The log average of the distance is used because observed noise is primarily a logarithmic function of distance (spherical spreading). For this example, the calculated value corresponding to one side of the 95% confidence interval for the difference between the observed noise and INM calculations is then added to the nominal noise value. An example of this confidence interval is shown in Figure 2-2 in the lower right-hand figure as a sidewise "I." Using a linear interpolation scheme again, the thrust corresponding to the noise value resulting from the addition is calculated, again using the log average of the CPA distance. The resulting value is a calculated thrust (revised estimate) corresponding to the observed noise as viewed by the INM. This procedure is repeated for the other side of the 95% confidence interval.

2.3 Investigating Empirical Models for Noise Exposure

Since the initial analysis of the noise exposure data and the computation of the INM sensitivity to thrust variations had indicated problems with certain of the basic INM noise curves,

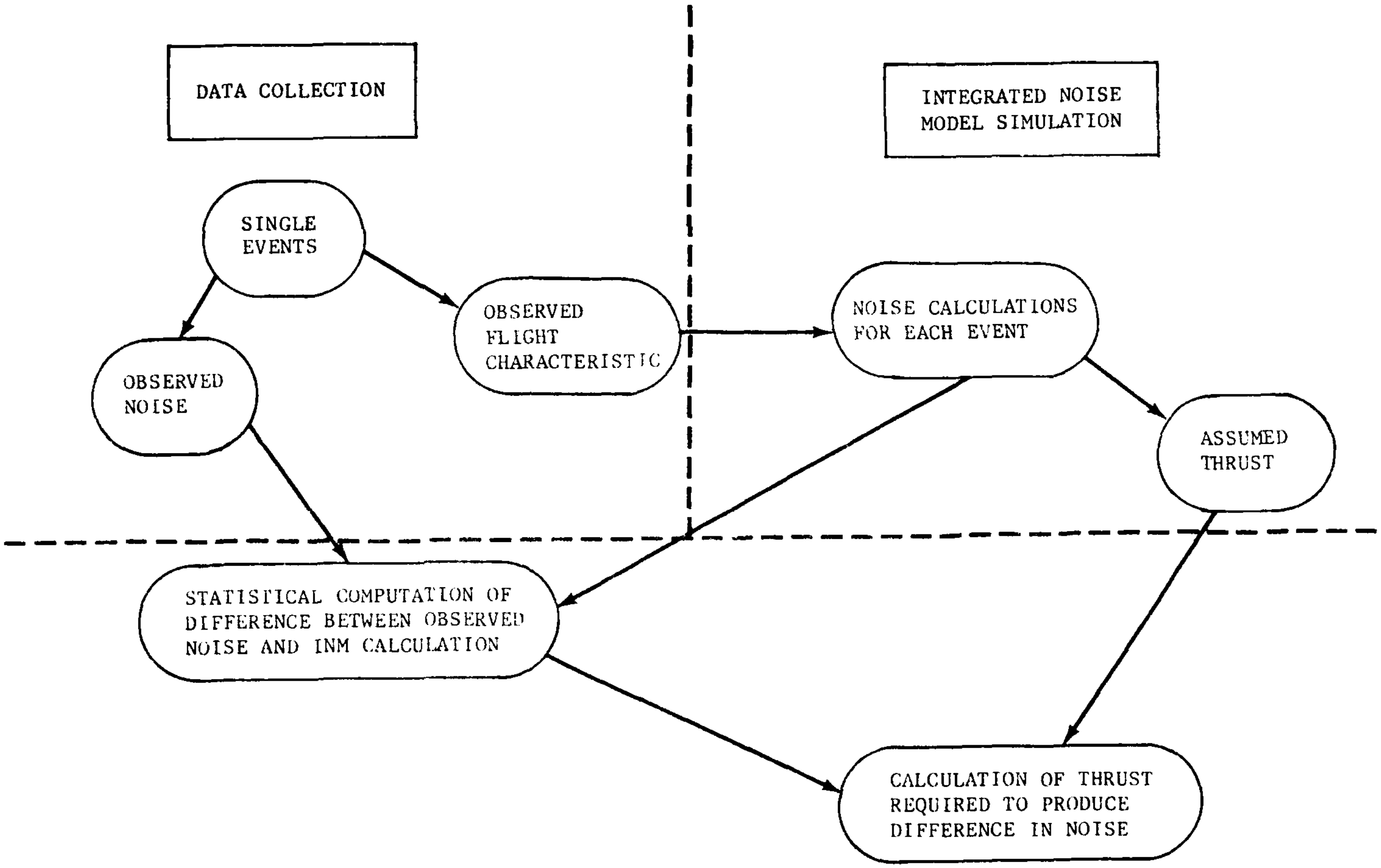


FIGURE 2-4
THRUST SENSITIVITY METHODOLOGY

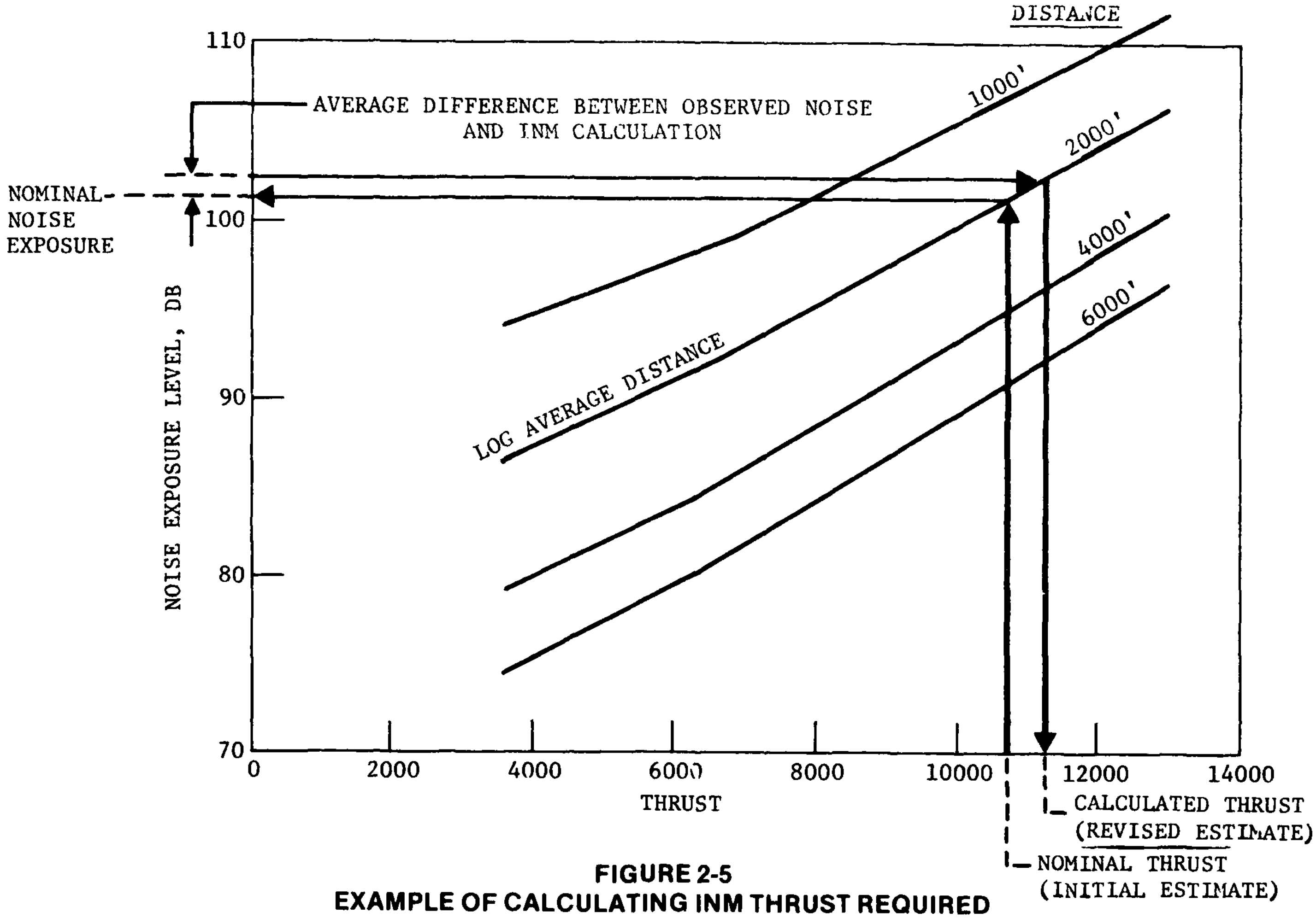


FIGURE 2-5
EXAMPLE OF CALCULATING INM THRUST REQUIRED TO AGREE WITH OBSERVED NOISE FOR 727

it was decided to investigate the mathematical values isolated from the influence of INM form describing observed noise calculations by computing empirical noise curves from the observed data. These empirical curves could then be compared with the corresponding INM curves, and significant differences noted.

As illustrated in Figure 2-6, for each aircraft type and operation there were four steps leading to the comparison of the INM curve and the empirical curve. First, the variables for each set of data were analyzed using a stepwise linear regression procedure to determine those variables statistically significant in estimating the noise level. Second, from the series of regression models output by the stepwise procedure, an appropriate model was chosen as the empirical curve. Third, its statistical validity was examined to determine whether or not the sample was normally distributed. Fourth, whenever the sample was determined to be normally distributed, a confidence region of at least 95% was computed about the curve to portray the possible variation in the empirical log-linear relationship. Finally, the empirical curve was graphically compared with the corresponding noise curve from the INM data base.

2.3.1 Variables Tested for Significance in Estimating Noise Values

For each noise exposure measurement, five variables were also calculated at the aircraft's closest point of approach (CPA). These variables were: slant-range distance, altitude, velocity along track, vertical velocity, and elevation angle. (The method by which these variables were computed is outlined in Appendix A.) Slant-range distance, altitude, velocity along track, and elevation angle are variables which relate to the physics of noise propagation and are used in the INM algorithm in calculating noise. Vertical velocity relates to either the climb or the descent gradient and was included in the analysis on an exploratory basis to determine whether or not the effect of vertical velocity would be significant. In addition, three transformations of these quantities were included as variables: $\log_{10}$ (CPA distance), $\log_{10}$ (CPA velocity), and $\log_{10}$ (CPA elevation angle). Indicator variables for each monitor site were also included to check for possible differences in measurements between the sites. The use of indicator variables is explained in Appendix B.

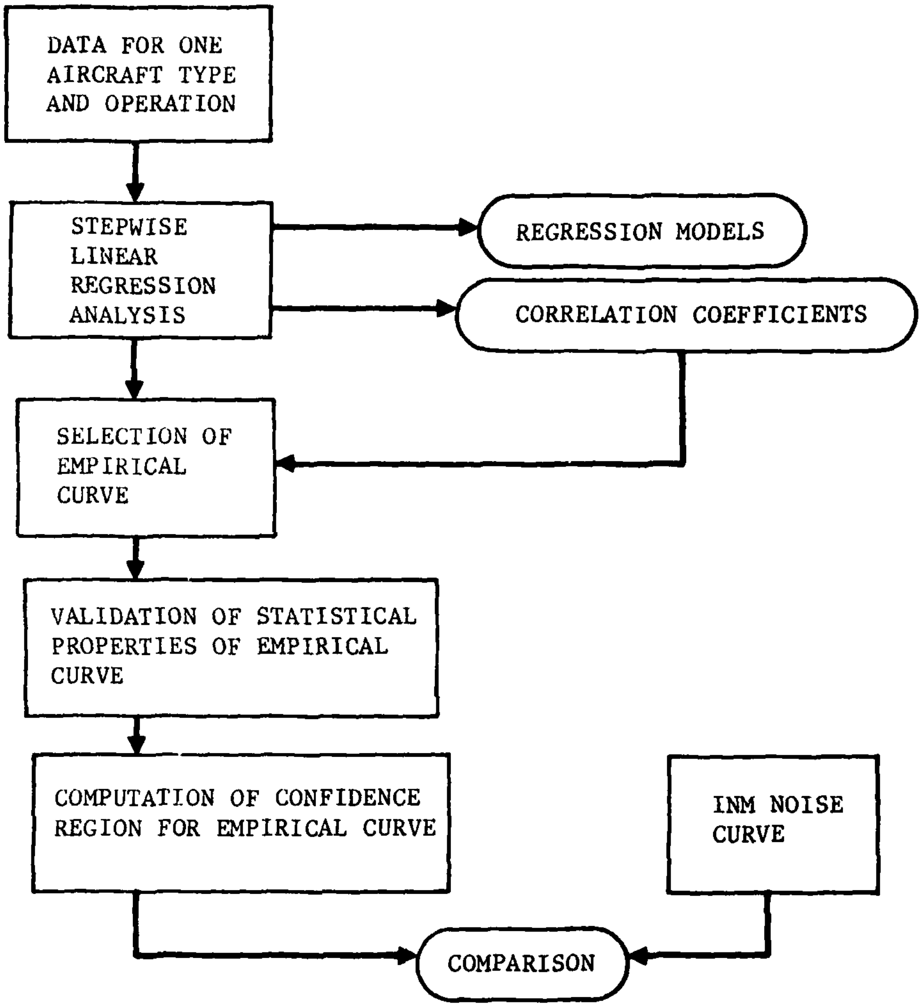


FIGURE 2-6
METHODOLOGY OF EMPIRICAL AND INM NOISE CURVE COMPARISON

2.3.2 Stepwise Regression Procedure

In order to determine those variables significant in estimating the noise levels and the functional form of their relationships, a powerful statistical technique, stepwise linear regression, was employed.

Starting with the single most significant independent variable, these regression models are built, as the name implies, in a stepwise fashion. At each step the procedure seeks to add a variable or to interchange a variable in the model with a variable not in the model in order to improve the least squares fit of the regression line. The procedure terminates when there are no more significant variables in the data. (The statistical details are given in Appendix B.) Thus, the final output of the procedure is a sequence of models, each being a better fit of the data than the ones preceding it. Various statistics about each model are also provided.

2.3.3 Confidence Regions for the Empirical Noise Curves

A confidence level region of at least 95% may be computed for a regression curve using the technique described in Appendix B, if the residuals are normally distributed (the Kolmogorov-Simirnov statistic is used to test for normality. In a few cases, the residuals departed slightly from normality, implying that while the estimate of the regression curve was still correct, confidence regions could not be computed in the usual fashion (Reference 5).) These confidence regions have the following interpretation: If data were collected 100 times while holding the values of the independent variables at the same levels observed in the samples, at least 95 of those 100 times one would expect the empirical noise curve to lie within the bounds of the confidence region.

2.3.4 Comparison of Empirical Noise Curves with the INM Noise Curves

Once the empirical noise curves had been computed, each was graphically compared with the appropriate INM curve(s) whenever possible. Since the INM curves express the noise level as a function of the distance at closest point of approach, the only empirical noise curves that were graphically comparable were those which included either CPA distance or $\log_{10}$ (CPA distance) as an independent variable.

When the empirical noise curve was a function of a set of variables including one or more that were neither functions of the slant-range distance nor indicator variables, a graphical comparison was more difficult. In order to make any graphical comparison whatsoever, some constant value of the variables (other than slant-range distance) must be chosen for use in the graph. In an attempt to select a generally representative value while not overfitting the curve to the data at hand and losing the desired generality, the median observed value of the variables (other than slant-range distance) was selected. For example, the empirical NEL curve for the DC-8-55 arrivals resulting from a step-wise linear regression analysis was

$$\text{NEL} = 178 - 24 * \text{LOG}_{10}\ (\text{CPA DISTANCE}) + .006 * (\text{CPA VERTICAL VELOCITY})$$

Using a CPA vertical velocity of -720 feet per minute, the curve graphed for comparison was actually

$$\text{NEL} = 174 - 24 * \text{LOG}_{10}\ (\text{CPA DISTANCE}).$$

A further problem in comparing such curves occurs with the interpretation of confidence regions. In some instances, these confidence regions are three or more dimensional, and as such, cannot be accurately graphed in two dimensions. The equations of the empirical noise curves and the sample sizes for all sets of data examined may be found in Appendix C.

The stepwise linear regression analysis is a statistical technique which focuses on the structure of simultaneous relationships among three or more variables. The objective of this technique is to search for the best possible simultaneous relationship between the observed noise and other correlated variables. Mathematically, these relationship can be determined. However, in simplifying these relationships, as in relating observed noise to only slant-range distance, some secondary relationships may be obscured. This makes interpretation of the data more difficult.

3. RESULTS

There are three independent methods of assessing the agreement between INM calculations and observed noise values. The first method, the statistical treatment of paired differences, provides an average difference over the range of CPA distances involved. The second method, the noise-thrust mapping procedure determines the thrust needed to produce the observed noise, and provides an indication of the capability of the model to simulate the observed noise without changes to the noise curves. The third method, the regression analysis and comparison of noise curves, enumerates and quantifies the effect of the variables used in the noise calculations and also determines the mathematical form of the functional relationships. The regression analysis provides a method for changing or redefining the noise curves.

Over 6000 single-event noise measurements (measured noise for an aircraft flyover abeam a monitor site) were taken and paired with calculations from the INM for statistical comparison. The observations were categorized by aircraft type, monitor site, and type of flight operation, i.e., departure or arrival. The events for each airport, for each aircraft type and each flight operation were combined for grouped statistics. The aircraft types were then arranged in three groups: four engine narrow body aircraft, two/three engine narrow body aircraft, and wide body aircraft.

For each aircraft type, a noise-thrust mapping procedure was performed for each monitor site and flight operation. The estimated values of the thrust were acquired from the statistical treatment of paired differences. For purposes of comparison with the thrust assumptions, the INM thrust profiles were provided for takeoff, climb and arrival operations. Each value was computed from the same sample from which the NEL differences were computed.

For nineteen of the twenty-eight sets of data examined using the methodology discussed in Section 2.3, the empirical noise curves were determined. The charts describing these curves are found in Appendix C. Note that the curves are only compared for the observed range of the distance. Since the empirical curves are regression lines and consequently are sensitive to extreme points, the curves cannot be assumed to be valid outside of this observed range.

Prior to discussing the data case by case, two general observations should be made. First, the data for arrivals was less well behaved than that for departures, i.e., using the variables tested, arrival noise levels were less predictable. Of the fourteen sets of arrival data examined, empirical curves could be found for only three. In those empirical curves not comparable to the INM curves, the consistently important variables were altitude, velocity, and $\log_{10}$ (velocity). One possible explanation for the more erratic behavior of the arrival data is the greater impact of ambient noise on the measured noise. During the approach or landing phase, the aircraft is using much less thrust than during the takeoff phase, and subsequently, much lower noise values are observed during landing. The ambient noise, if correlated or labeled as aircraft noise, could introduce a much higher and erroneous value than the actual aircraft noise value. Another possible explanation for the more erratic behavior of the arrival data is that the pilots are varying the aircraft thrust during the landing phase. These thrust adjustments could be for a change in configuration (lowering landing gear or flaps) or for maintaining final approach airspeed.

A second general observation is that the data gathered at National Airport was significantly less well behaved than that gathered at Dulles Airport for both departures and arrivals. Although some empirical noise curves could be determined from the National departure data, these curves (as measured by the correlation coefficient) did not fit their respective data as well as did the Dulles empirical curves. Furthermore, no statistically valid empirical noise curves whatsoever could be determined from the National arrival data. The statistically less well behaved data at National Airport may be caused in part by the greater dispersion in the ground tracks abeam the monitor sites as depicted in Figures 1-5 and 1-6. (Monitor sites located at greater distances from the runway threshold tend to have greater dispersion associated with the ground tracks. The dispersion in ground tracks, in turn, causes more variability in the observed noise because of variations in thrust, descent or climb rates, and shielding from different flight attitudes).

The results will now be presented by aircraft type groupings. A summary of these results is provided in Section 4.

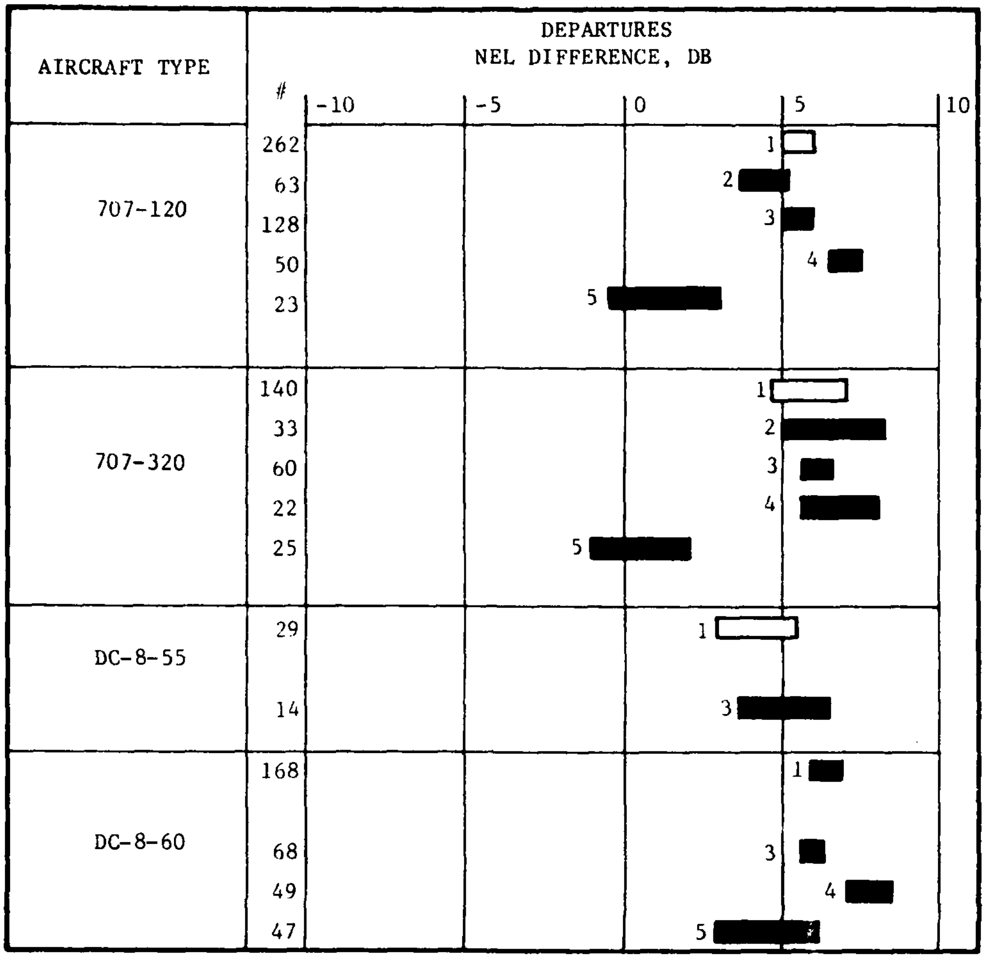
3.1 Four Engine Narrow Body Aircraft

Data on four different types of four engine narrow body aircraft was gathered at Dulles Airport. Case by case synopses follow.

3.1.1 Departures (Four Engine Narrow Body Aircraft)

The 95% confidence intervals for mean differences between observed noise and INM calculations are shown in Figure 3-1. The average difference for monitor sites other than Centreville for the different aircraft types is in the range from 3 to 7 dB. The sites all seem to be grouped together except for Centreville. The uniqueness of Centreville is discussed at the end of this section. Opposite each aircraft type labeled in Figure 3-1 is given first the sample sizes (#) of the observations and then the 95% confidence intervals for the mean differences for either individual monitor sites (bars labeled "2" thru "5"), or the combined differences of all the monitor sites (bars labeled "1"). Sample sizes of observations less than 10 are not shown. For example, for 707-120 aircraft, there were a total of 262 observations for all the sites. Of these 63 observations were for Dulles North. (The location of Dulles North was previously shown in Figures 1-3 and 1-4.) For Dulles North, there is a 95% chance that the mean difference between the observed noise and the INM calculations of the same flyovers is in the range of about 3 to 5 decibels. In other words, this statistic says that observations at Dulles North are, on the average, 3 to 5 decibels higher than the INM would calculate for the same flyovers.

Figure 3-2 shows both the calculated thrust resulting from application of the noise-thrust mapping procedure to the mean differences of Figure 3-1, and also the takeoff and climb thrust profiles resident in the INM data base. The family of curves labeled "takeoff thrust" and "climb thrust" correspond to aircraft profiles of varying weights. The heaviest aircraft depicted in the INM data base would have its takeoff thrust maintained at the higher value for a longer distance from start of takeoff roll than would the lightest aircraft. The vertical bars shown in Figure 3-2 correspond one-to-one to mapped values of the mean differences from Figure 3-1. For example, the mapped differences for 707-120's at Dulles North equates to thrust values between about 15000 and 17000 pounds. Whereas the actual value of the thrust may not be important, the position of the mapped thrust value relative to the reference INM thrust curve is important. In this case, the mapped thrust is located above the takeoff thrust curve obtained from the INM data base. Since the takeoff thrust is theoretically the maximum thrust that an aircraft can use for any operation, the location of the mapped thrust above the takeoff curve indicates that there may be a problem with the INM takeoff curves themselves. The problem is that the INM cannot be adjusted to produce a calculated noise analagous to the noise observed at the monitor sites. In



ALTITUDES OF DEPARTURES >1500 FEET AGL

DATES: 3 MAY 78 - 8 NOV 78

LEGEND:
1 ALL DULLES SITES
2 DULLES NORTH
3 CHANTILLY
4 ARCOLA
5 CENTERVILLE

\# SAMPLE SIZE

FIGURE 3-1
DIFFERENCES BETWEEN OBSERVED NOISE AND INM CALCULATIONS FOR FOUR ENGINE, NARROW BODY DEPARTURES

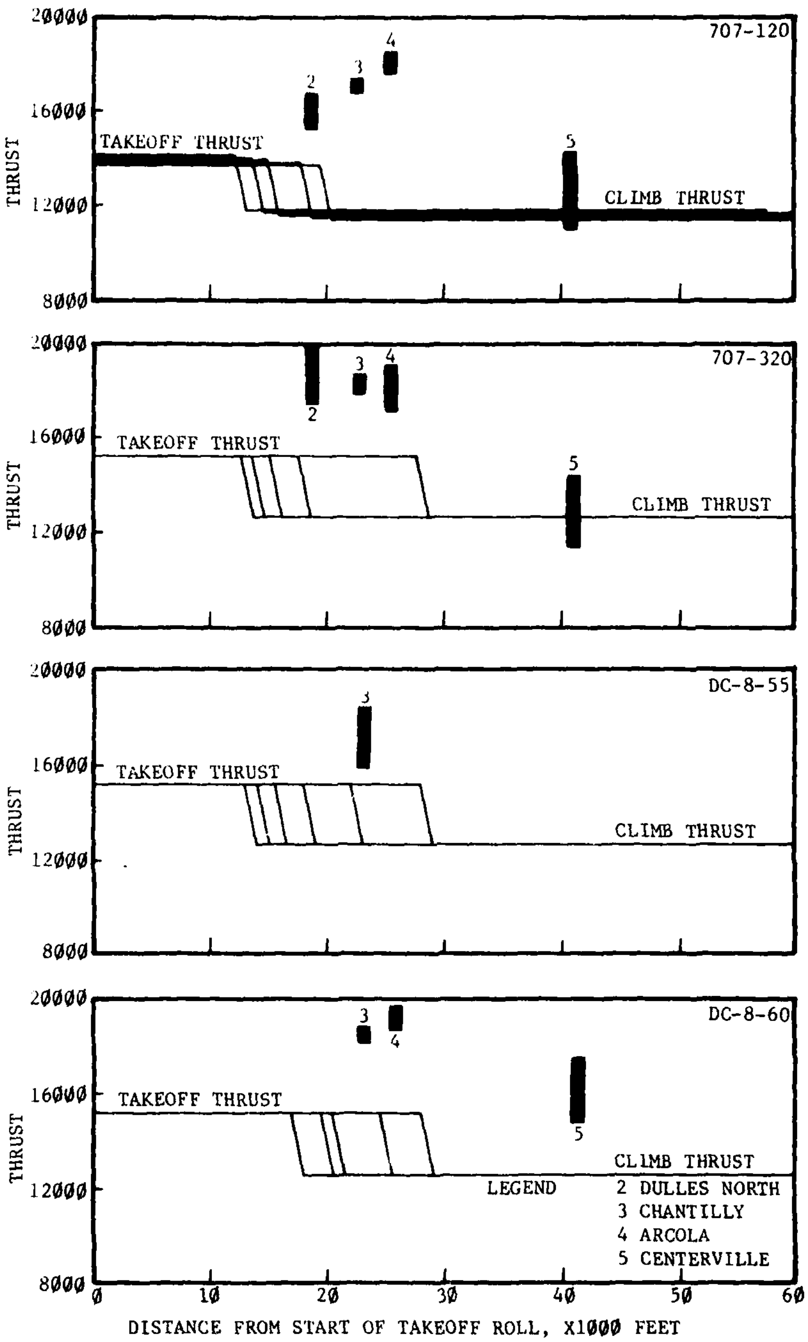


FIGURE 3-2
CALCULATED THRUST FOR
FOUR ENGINE, NARROW BODY DEPARTURES

sites. In general, results from all four engine narrow body aircraft, when mapped into the thrust regime, indicate that the required INM thrust necessary to produce the observed noise exceeds their respective takeoff thrusts.

Figure 3-3 shows a comparison of the empirical and INM noise curves. The INM noise versus distance curves (shown as solid lines) are obtained directly from the INM data base and have not been altered in any way. The empirical curves (shown as dash--dotted lines) are a result of an automated stepwise regression procedure. The samples used for the regression analysis were not a priori separated into any groupings. The groupings that evolved are a result solely of the automated statistical procedure. The 95% confidence interval for the empirical curves (shown as dashed lines) are shown whenever the statistical properties of the sample enabled its calculation. In general, the empirical curves for Dulles North, Chantilly and Arcola (a grouping selected by the automated regression procedure) are 2 to 3 decibels higher than the INM curve for takeoff. The empirical curves for Centreville are very near the INM curve for climb.

The reason for the uniqueness of Centreville is suggested in Figure 3-2, which depicts the calculated thrust which would be required by the aircraft to produce the observed noise. In Figure 3-2, both the takeoff thrust and climb thrust are shown in relationship to the calculated thrusts as a function of distance from the start of the takeoff roll. Comparing the calculated thrusts with the nominal thrust profiles from the INM suggests that the aircraft are not cutting back to climb thrust until they are at downrange distance of more than 28,000 feet. An important observation to be made from Figure 3-2 is that the calculated thrusts for the observed noise abeam the Dulles North, Chantilly and Arcola sites all exceed the takeoff thrusts for their respective aircraft types. The altitudes of all the aircraft in these samples are above 1500 feet, which means that if the aircraft were following standard climbout procedures, they all should be at climb thrust.

The uniqueness of Centreville is substantiated by the comparison of empirical noise curves and the INM curves in Figure 3-3. The stepwise regression procedure selected Centreville as being statistically different from the other three sites for 707-120, 707-320 and DC-8-60 aircraft. For the DC-8-55 sample, the observations at Centreville were not separated out from the rest of the sample. The message from three separate approaches says that Centreville is unique as a noise monitor site. A partial explanation for this uniqueness is that aircraft are maintaining takeoff thrust longer during climbout than assumed. Since

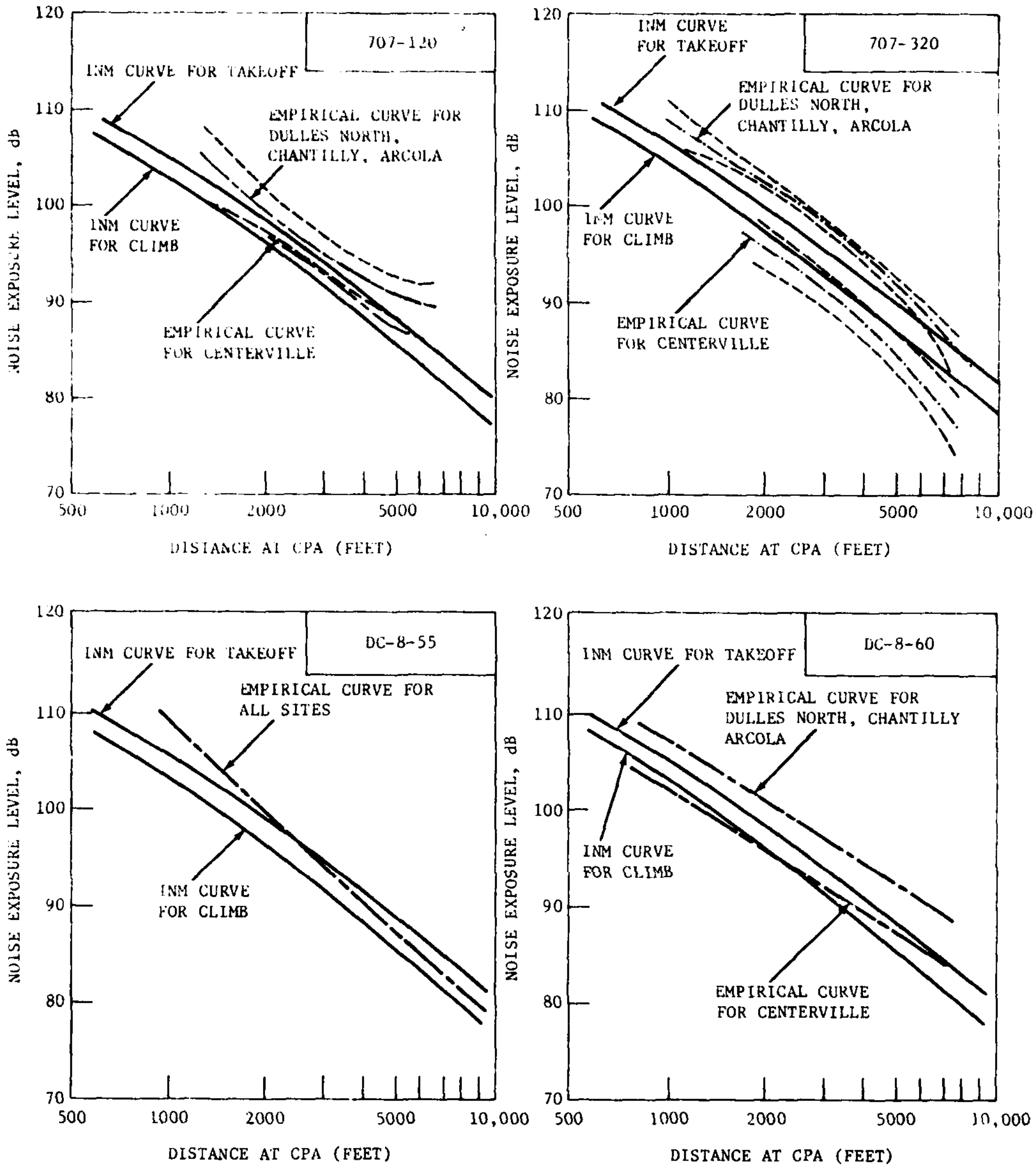


FIGURE 3-3
EMPIRICAL AND INM NOISE CURVES FOR FOUR ENGINE, NARROW BODY DEPARTURES

Centreville is a greater distance from the start of takeoff roll (41000 feet versus approximately 23000 feet for the other sites), nearly all aircraft have reduced their thrust levels to those specified for climbout, whereas at the closer-in sites, the thrust reduction has not been accomplished by most aircraft.

3.1.2 Arrivals (Four Engine Narrow Body Aircraft)

The average differences between the observed noise and INM calculation shown in Figure 3-4 are in the range of 1 to 6 dB, with DC-8-60's having the best agreement and 707-320's having the worst agreement. In contrast to the departures, arrival data at Centreville are not markedly different from the other three sites.

Although the range of the differences shown in Figure 3-4 are generally 2 to 3 dB, when these intervals are transformed to calculated thrust for the observed noise, the intervals become much larger than those for departures as shown in Figure 3-5. These large intervals suggest that the range of approach thrust varies substantially. However, part of problem of interpreting the arrival data may be in the INM curves used to calculate the thrusts. Since the calculated thrust are substantially higher than the INM approach thrust curve, this suggests that the INM curves are not correct. Since the approach thrust values were obtained from manufacturer specifications, the INM noise curves corresponding to a particular thrust are suspect.

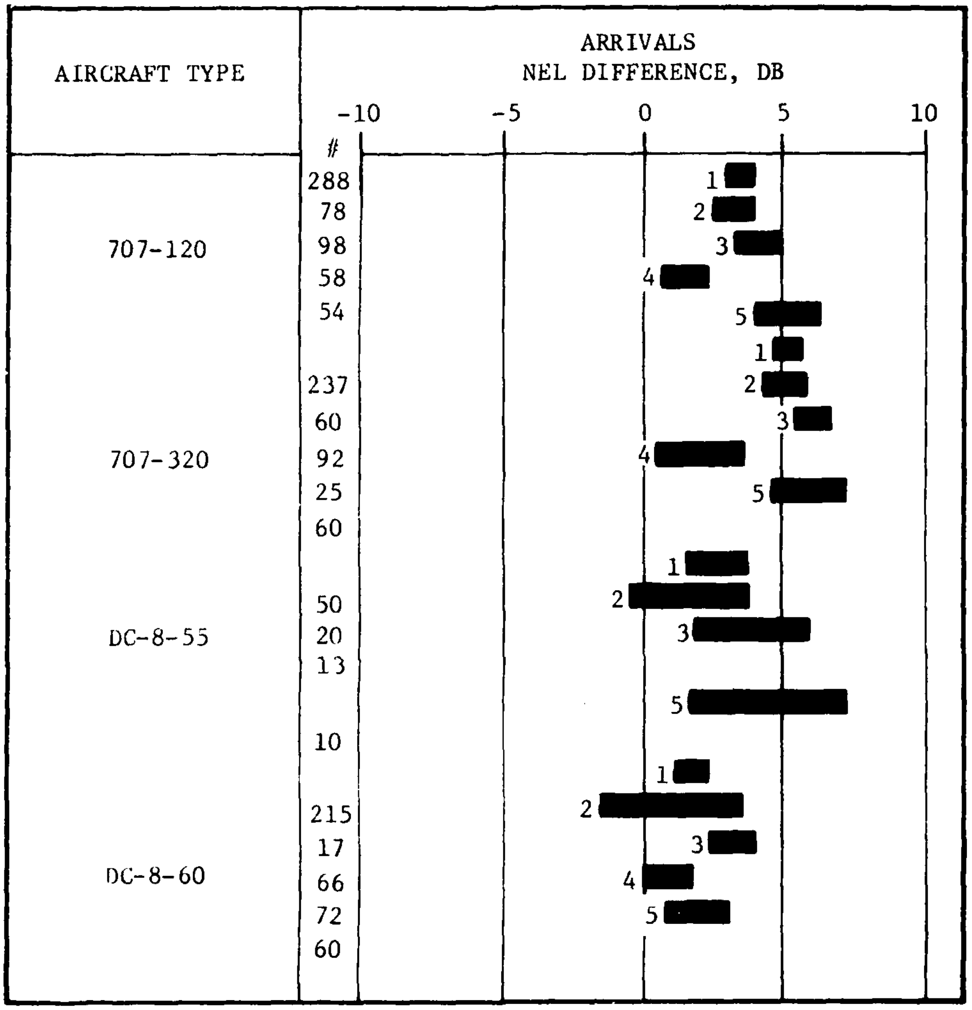
The results of the regression analysis (Figure 3-6) show that the empirical curve for DC-8-55 arrivals is approximately 2 to 4 dB higher than that calculated by the noise model. The empirical curves for the other three aircraft types are not shown because they are not mathematical functions of CPA distance. This problem is treated in Section 3.4.

3.2 Two/Three Engine Narrow Body Aircraft

Data on three different types of two and three engine narrow body aircraft was gathered at Dulles Airport, while data on four such aircraft types was gathered at National Airport. Case by case synopses follow.

3.2.1 Departures (Two/Three Engine Narrow Body Aircraft)

Dulles and National departures are not comparable directly, because of the difference in takeoff procedures. At both airports, takeoff power should be maintained to an altitude of 1000 feet. However, above 1000 feet, procedures at Dulles call for departures to maintain climb power, while procedures at National call for departures to reduce thrust to a setting required to maintain 500 feet per minute climb.



DATES: 3 MAY 78 - 8 NOV 78

LEGEND: 1 ALL DULLES SITES
2 DULLES NORTH
3 CHANTILLY
4 ARCOLA
5 CENTERVILLE

SAMPLE SIZE

FIGURE 3-4
DIFFERENCES BETWEEN OBSERVED NOISE AND INM CALCULATIONS FOR FOUR ENGINE, NARROW BODY ARRIVALS

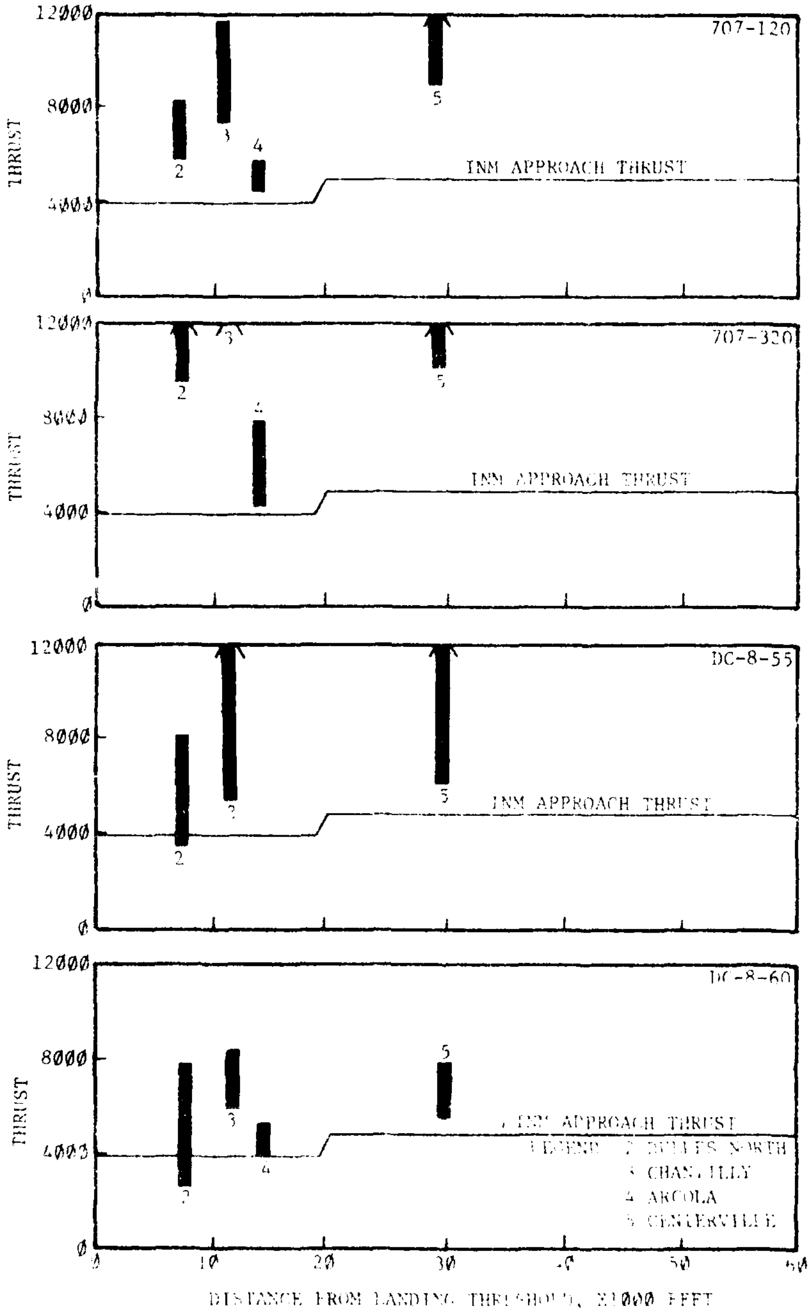


FIGURE 3-5
CALCULATED THRUST FOR
FOUR ENGINE, NARROW BODY ARRIVALS

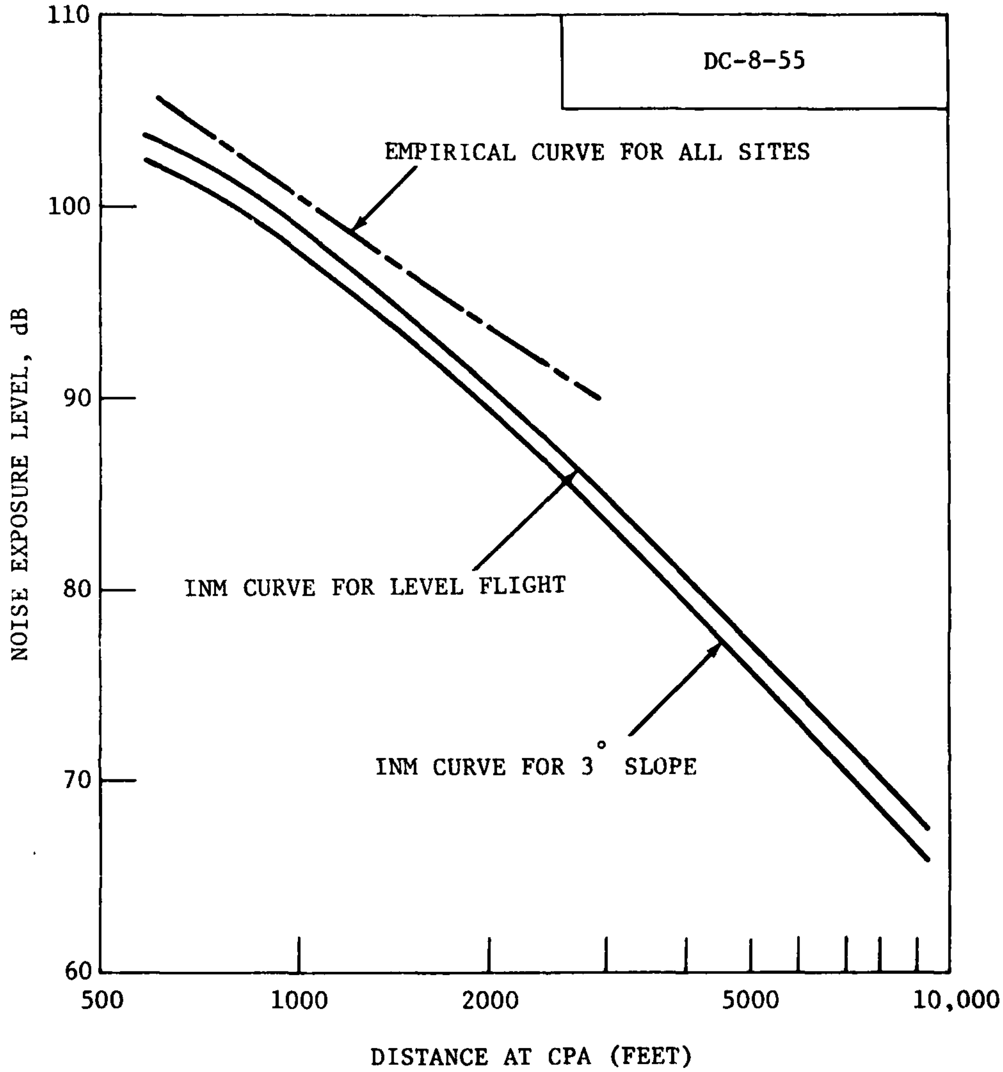


FIGURE 3-6
EMPIRICAL AND INM NOISE CURVES FOR FOUR ENGINE, NARROW BODY ARRIVALS

Figure 3-7 compares the average vertical velocity at CPA for all departures at Dulles and National Airports. The vertical velocities for aircraft departures from National do not differ very much from those seen at Dulles. In order to maintain the same climb rate, a similar thrust setting for the same aircraft type is required. This contention is also supported by the results of the following three separate analyses.

In general, observed noise levels at Dulles for DC-9, 727 and 737 are lower than the INM calculations. One possible explanation for this observation is that a portion of the aircraft in the sample are equipped with quieter, FAR 36 compliant engines. In this analysis, however, aircraft which have retrofit engines are not distinguishable from those which have standard engines. Thus, all aircraft are assumed to be equipped with standard engines.

The results of the statistical comparison for the differences between the observed noise and INM calculations for two and three engine narrow body aircraft are presented in Figure 3-8. The results for Dulles and National Airports are presented separately. The composite differences for Dulles sites indicate that the observed noise is 0 to 3 dB below the noise model calculations. Differences for Centreville are noticably different from the other sites at Dulles, with the INM calculations being 3 to 7 dB below the observed noise. The composite differences for National Airport indicate that the observed noise is 2 to 6 dB higher than the INM calculations. For National, differences for Old Town are noticably different from the other sites, with the observed noise being 7 to 10 dB higher than the INM calculations. Note that the differences for the two airports are measured with respect to different thrust assumptions.

Figure 3-9 shows the calculated thrust corresponding to the observed noise of Figure 3-8. The climb thrusts for Dulles departures are assumed to be higher than those for National departures. When the calculated thrusts for the two airports are presented on the same graph as a function of distance from start of takeoff roll, the apparent uniqueness of Centreville and Old Town becomes understandable. The distance from start of takeoff roll for Old Town is between the distances for Dulles North and Chantilly; similarly, Centerville is between Marlin Forest and Waynewood. These relative positions suggest that aircraft performance near Old Town is comparable to some Dulles sites and that aircraft performance near Centreville is comparable to some National sites.

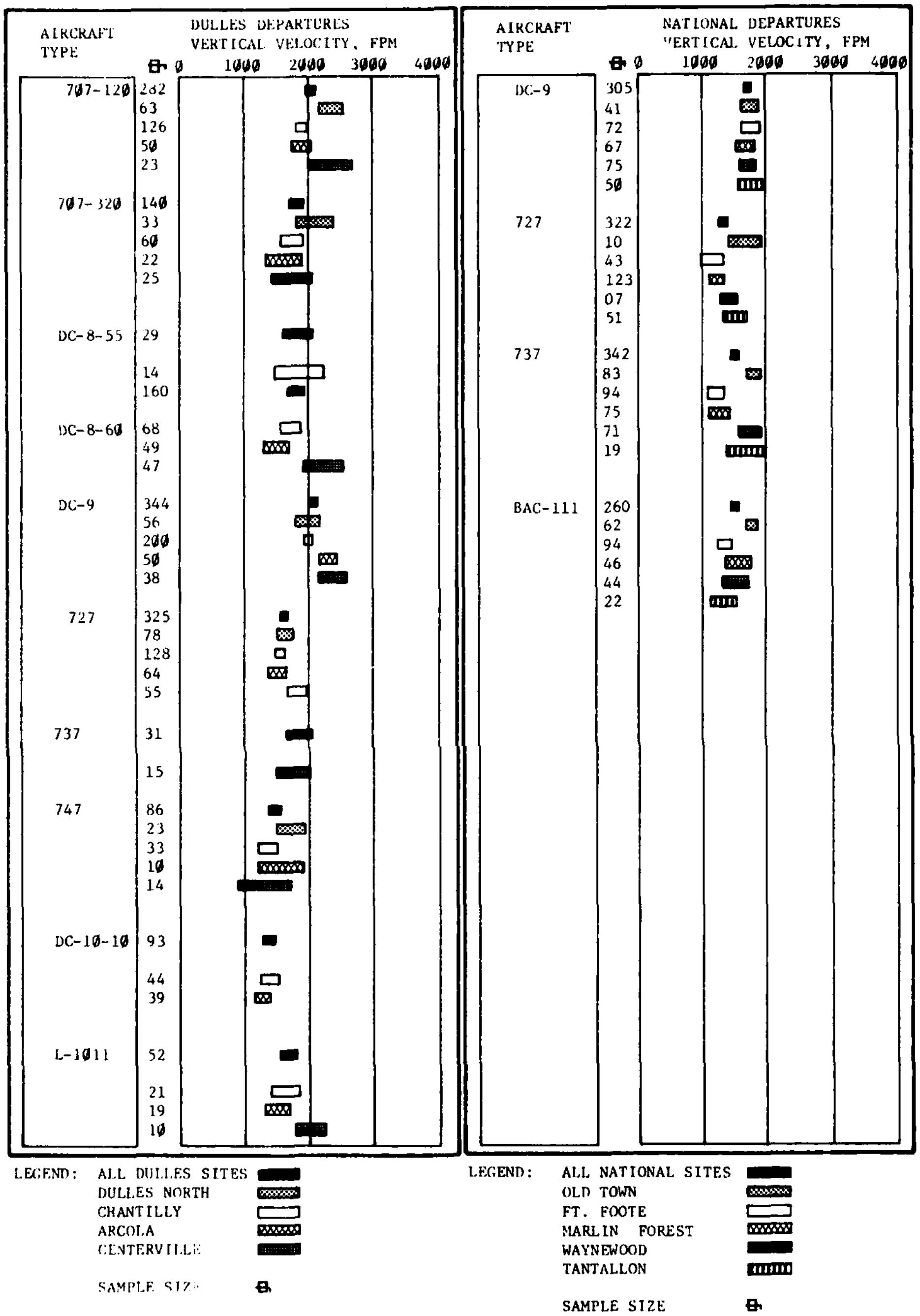
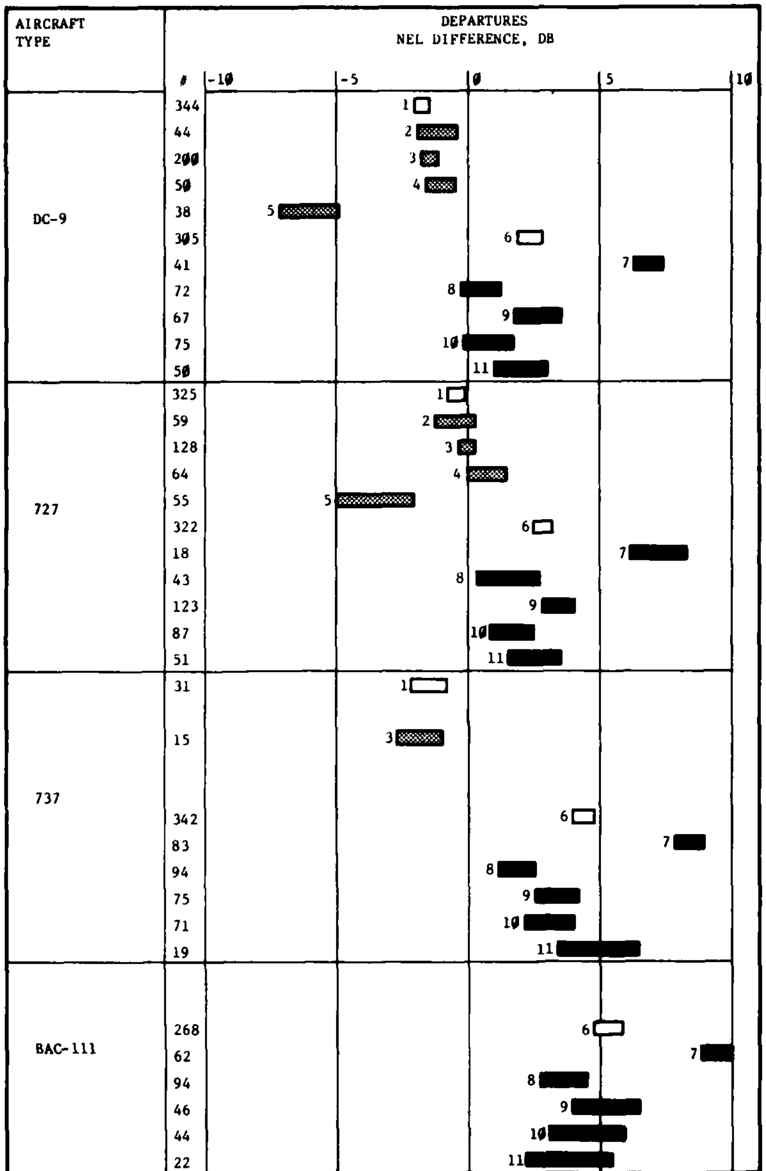


FIGURE 3-7
95% CONFIDENCE INTERVALS FOR AVERAGE CPA VERTICAL VELOCITY



ALTITUDES OF DEPARTURES > 1500 FEET AGL
DATES: 3 MAY 78 - 23 JAN 79

LEGEND:
1 ALL DULLES SITES
2 DULLES NORTH
3 CHANTILLY
4 ARCOLA
5 CENTERVILLE
6 ALL NATIONAL SITES
7 OLD TOWN
8 FT. FOOTE
9 MARLIN FOREST
10 WAYNEWOOD
11 TANTALLON

\# SAMPLE SIZE

FIGURE 3-8
DIFFERENCES BETWEEN OBSERVED NOISE AND INM CALCULATIONS FOR TWO/THREE ENGINE, NARROW BODY DEPARTURES

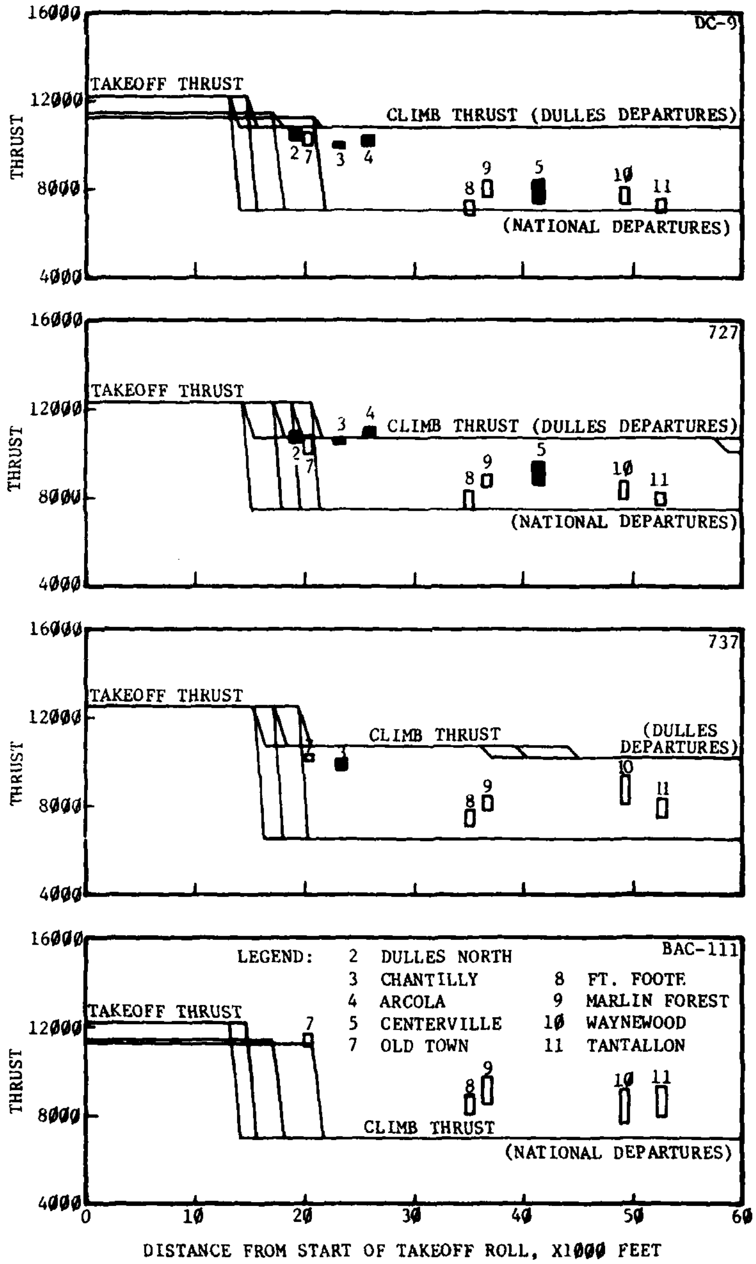


FIGURE 3-9
CALCULATED THRUST FOR
TWO/THREE ENGINE, NARROW BODY DEPARTURES

Figure 3-10 provides information concerning the statistical uniqueness of Old Town and Centreville. As an example, consider the empirical noise curves for DC-9 aircraft at Dulles and National in Figure 3-10. As a result of the stepwise regression analysis, the empirical curve for Centreville was selected as being statistically different from the other sites at Dulles Airport. Likewise, Old Town was selected as being different from the other sites at National Airport. Figure 3-10 suggests that the empirical curves for Dulles North, Chantilly, Arcola and Old Town should be compared with the INM curve for takeoff and Centreville, Ft. Foote, Marlin Forest, Waynewood and Tantallon should be compared with the INM curve for climb.

In some cases, as the DC-9 and 737 departures at National, the noise versus distance relationships in the range from 5,000 to 10,000 feet seemed abnormally high in relationship to the INM noise curves. These observations may be the result of nearby automobile and truck traffic noise near the monitor site and are currently being investigated. High noise readings at the greater distances would cause the decreased slope of the noise curves shown for these two cases.

3.2.2 Arrivals (Two/Three Engine Narrow Body Aircraft)

The statistical treatment of paired differences shown in Figure 3-11 indicates that arrival procedures for the two airports are similar. These differences are measured relative to the same arrival profile. The DC9 and 727 differences are very similar, with the average difference in the range from -1 to 3 dB. The average observed noise for 737s is about 2 to 3 dB below the INM calculations. There is considerable variation in the calculated thrusts, as shown in Figure 3-12. In an attempt to explain these differences, one must consider typical arrival profiles as discussed in Section 2.1.1.

The following paragraph describes a scenario as a possible explanation to the thrust patterns as seen in Figure 3-12. The thrust for Tantallon is low because aircraft are still descending and have not stabilized at an approach altitude. Aircraft are in level flight abeam Waynewood, Centreville and Marlin Forest. Aircraft then begin descent for landing and reduce thrust abeam Ft. Foote to allow the airspeed to decrease to final approach speed. Aircraft then adjust thrust abeam the remaining sites to maintain descent along the glide slope.

The arrival data from National Airport yielded no valid empirical noise curve for either DC-9s, 727s, 737s, or BAC-111s. Using the regression analysis, the noise level could not be predicted using slant-range distance.

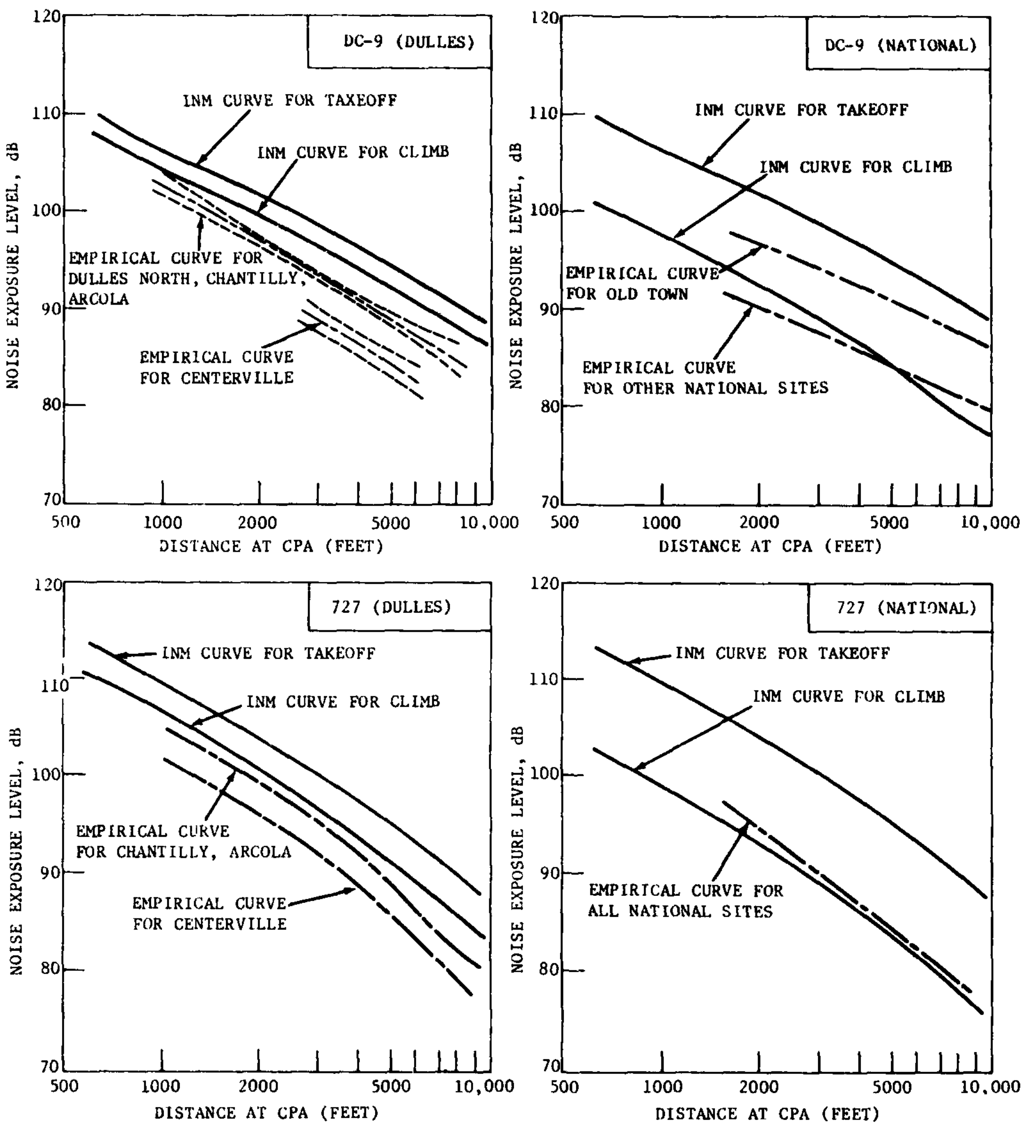


FIGURE 3-10
EMPIRICAL AND INM NOISE CURVES FOR TWO/THREE ENGINE, NARROW BODY DEPARTURES

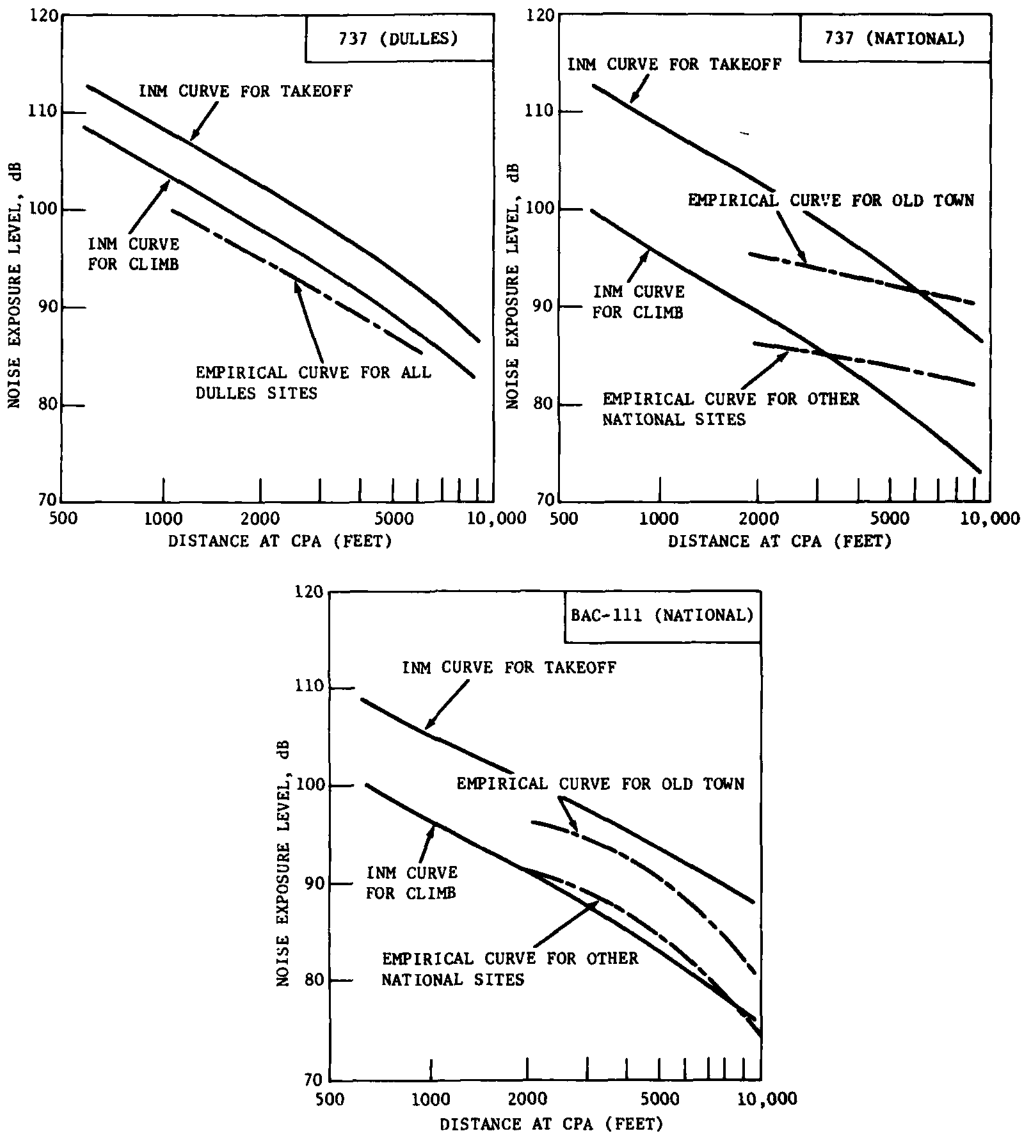
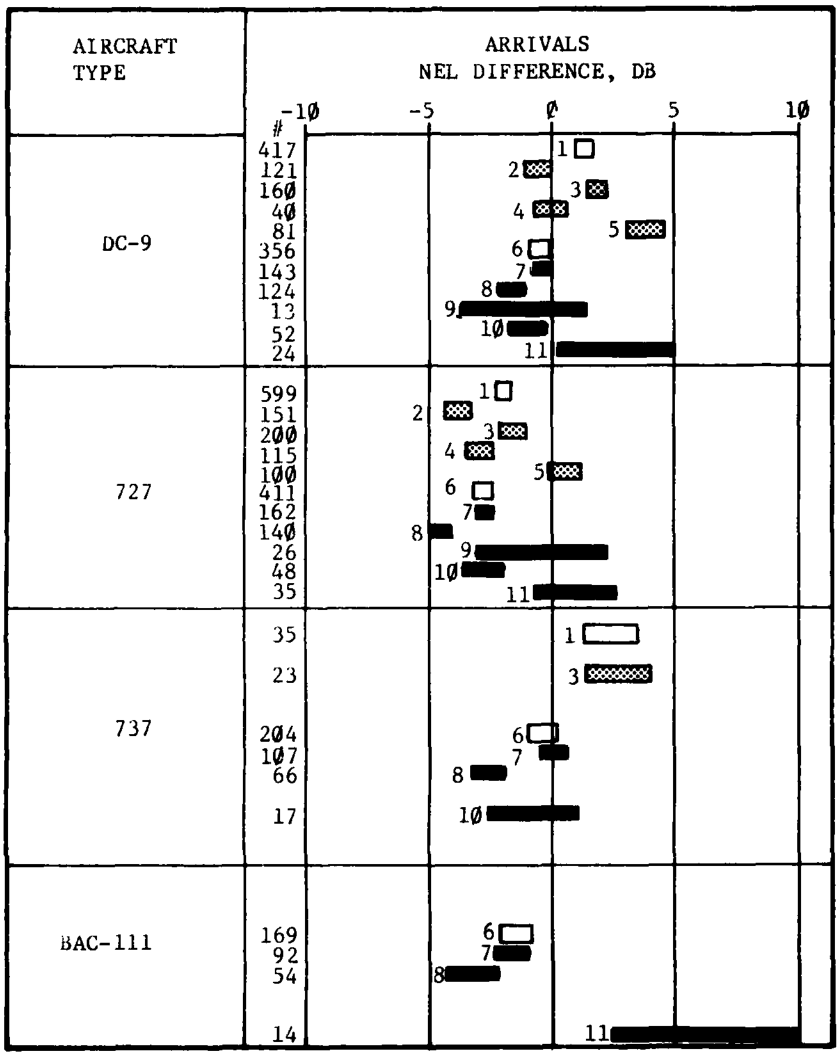


FIGURE 3-10
EMPIRICAL AND INM NOISE CURVES FOR TWO/THREE ENGINE, NARROW BODY DEPARTURES (CONTINUED)



DATES: 3 MAY 78 - 23 JAN 79

LEGEND:

1	ALL DULLES SITES	8	FT. FOOTE
2	DULLES NORTH	9	MARLIN FOREST
3	CHANTILLY	10	WAYNEWOOD
4	ARCOLA	11	TANTALLON
5	CENTERVILLE		
6	ALL NATIONAL SITES	#	SAMPLE SIZE
7	OLD TOWN		

FIGURE 3-11
DIFFERENCES BETWEEN OBSERVED NOISE AND INM CALCULATIONS FOR TWO/THREE ENGINE, NARROW BODY ARRIVALS

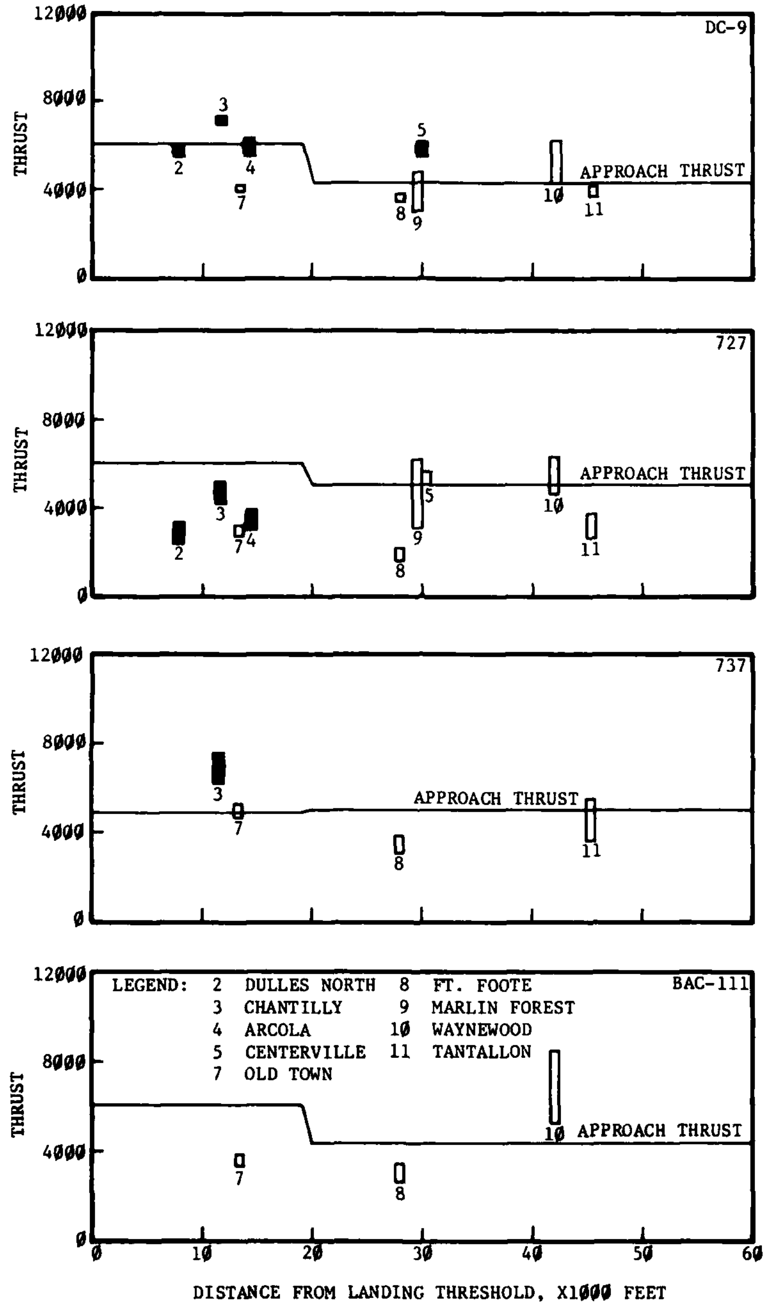


FIGURE 3-12
CALCULATED THRUST FOR
TWO/THREE ENGINE, NARROW BODY ARRIVALS

The arrival data from Dulles Airport was much better behaved although comparable noise curves were only computed for 727 and 737 arrivals. As shown in Figure 3-13, the 727 INM curve is up to 2 dB lower than the empirical curve up to distances of about 2000 feet and is then up to 2 dB higher than the empirical curve. The 737 INM curve is 3 to 4 dB lower than the empirical curve.

3.3 Three/Four Engine Wide Body Aircraft

Data on three different three and four engine wide body aircraft was gathered at Dulles Airport. Case by case synopses follow.

3.3.1 Departures (Wide Body Aircraft)

The results of the statistical comparisons for wide body departures are shown in Figure 3-14. The average observed noise value is between 2 and 5 dB higher than the INM calculation for wide body aircraft. The average observed value for 747s is 2 to 3 dB, for DC-10s is 3 to 4 dB and for L-1011s is 4 to 5 dB higher.

The calculated thrusts for departures resulting from the noise--thrust mapping procedure are shown in Figure 3-15. For the 747 example, 747-200s and 747-100s could not be distinguished by the methods used in this study. The INM has in its data base, thrust profiles for both of the types, however, and these are shown on the chart for comparison. The takeoff thrust for 747-200s is greater than 747-100s and exceeds the 95% confidence interval for thrust for Dulles North and Chantilly. This confidence interval overlaps the takeoff thrust for 747-100s. The calculated thrusts for DC-10s and L-1011s exceed the takeoff thrust for Chantilly and Arcola.

Comparable noise curves, as shown in Figure 3-16, were computed for all three aircraft types observed. The 747 INM noise curve is in reasonable agreement with the empirical curve graphed. For distances above 2000 feet, DC-10-10 INM takeoff curve is below the lower limit of the corresponding confidence region, while the INM climb power curve is within the confidence region. The L-1011 INM curves are 3 to 9 dB lower than the empirical curve graphed.

3.3.2 Arrivals (Wide Body Aircraft)

As shown in Figure 3-17, the average observed NEL value is between 5 and 6 dB higher than the INM calculation for wide body aircraft. The values are very consistent between the three wide bodies.

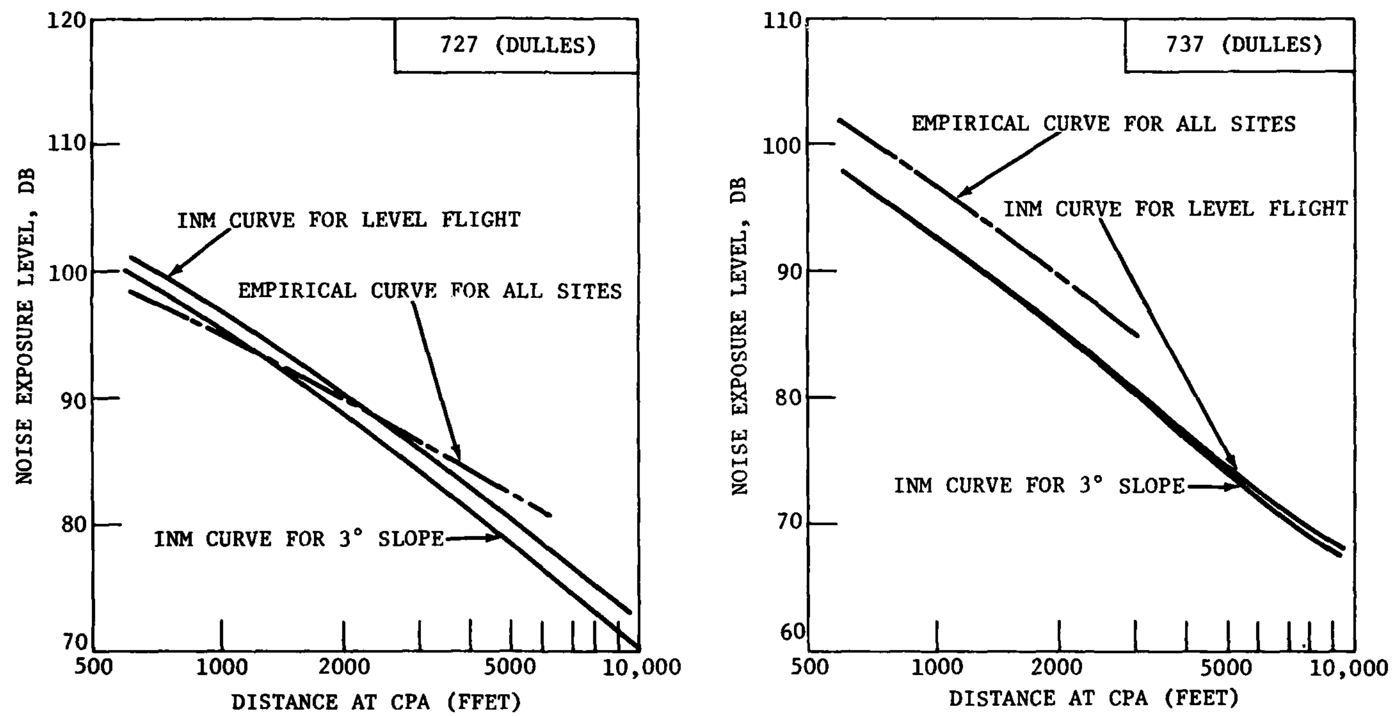
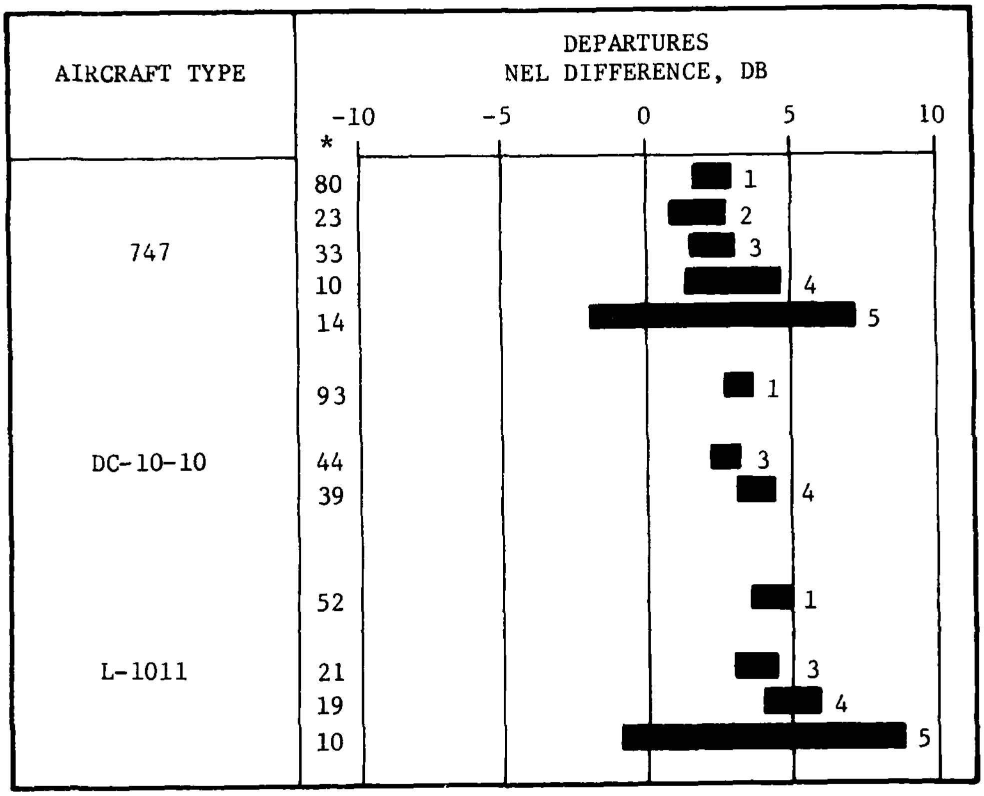


FIGURE 3-13
EMPIRICAL AND INM NOISE CURVES FOR TWO/THREE ENGINE, NARROW BODY ARRIVALS



ALTITUDES OF DEPARTURES > 1500 FEET AGL

DATES: 3 MAY 78 - 8 NOV 78

LEGEND: 1 ALL DULLES SITES
2 DULLES NORTH
3 CHANTILLY
4 ARCOLA
5 CENTERVILLE

* SAMPLE SIZE

FIGURE 3-14
DIFFERENCES BETWEEN OBSERVED NOISE AND INM CALCULATIONS FOR WIDE BODY DEPARTURES

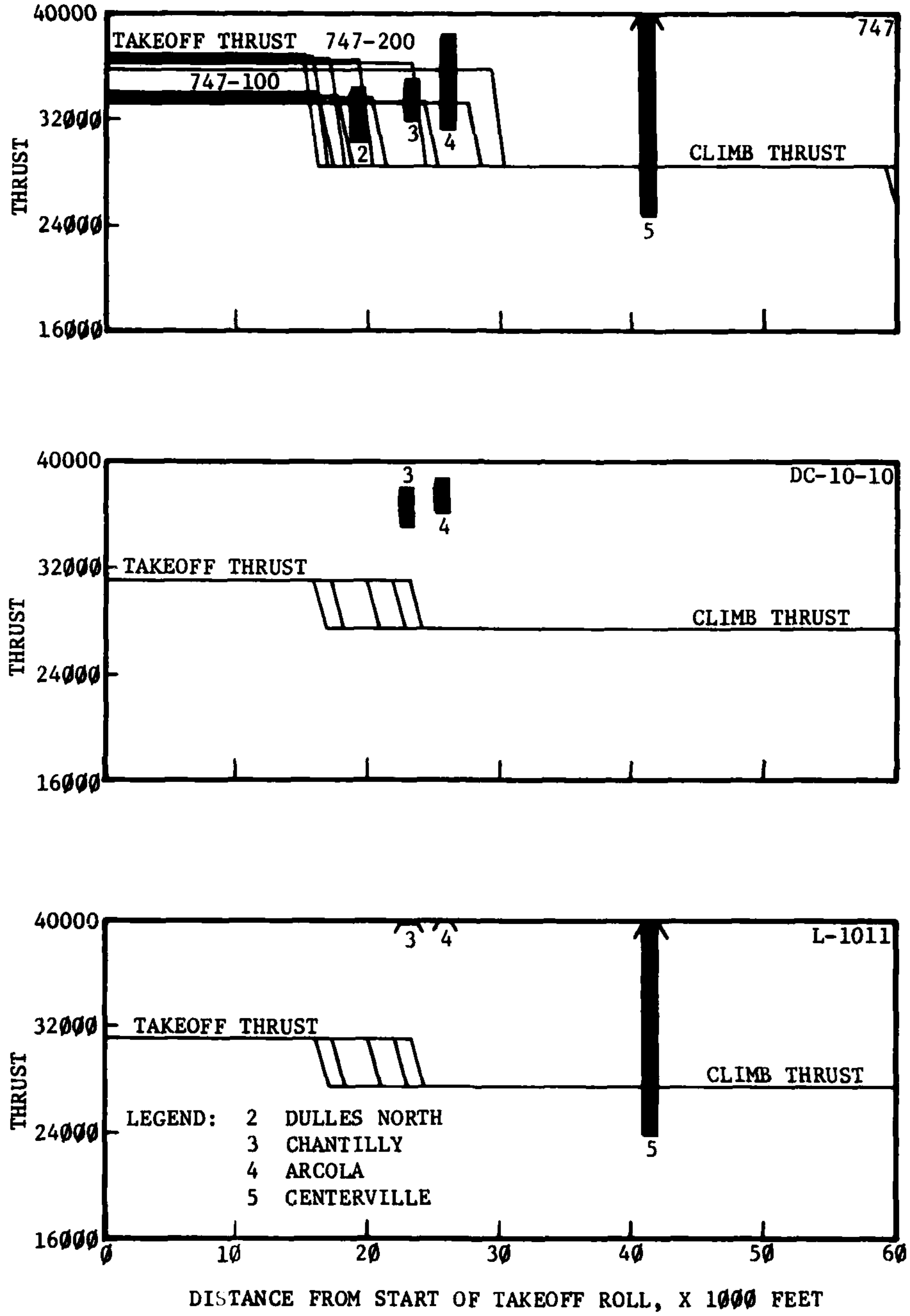


FIGURE 3-15
CALCULATED THRUST FOR WIDE BODY DEPARTURES

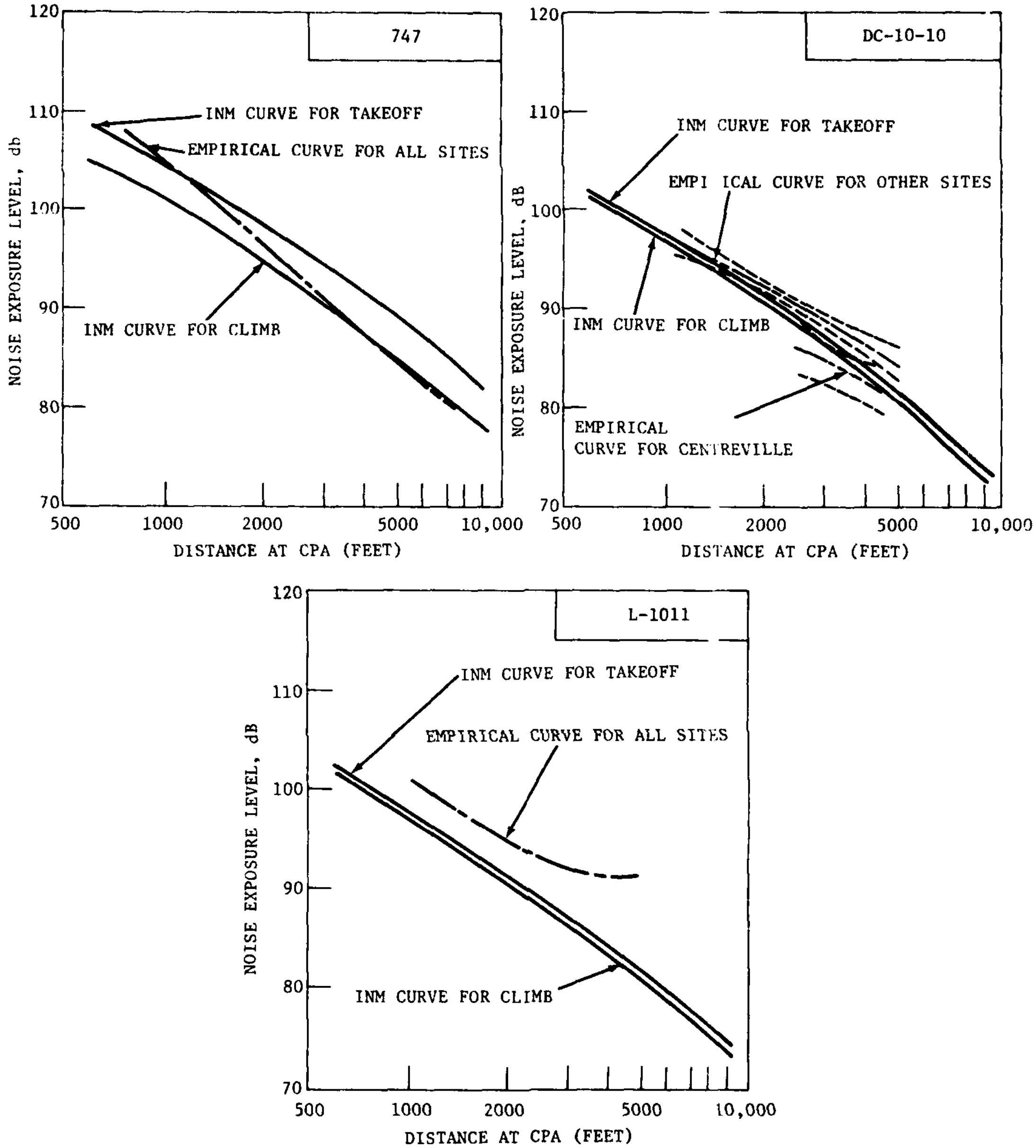
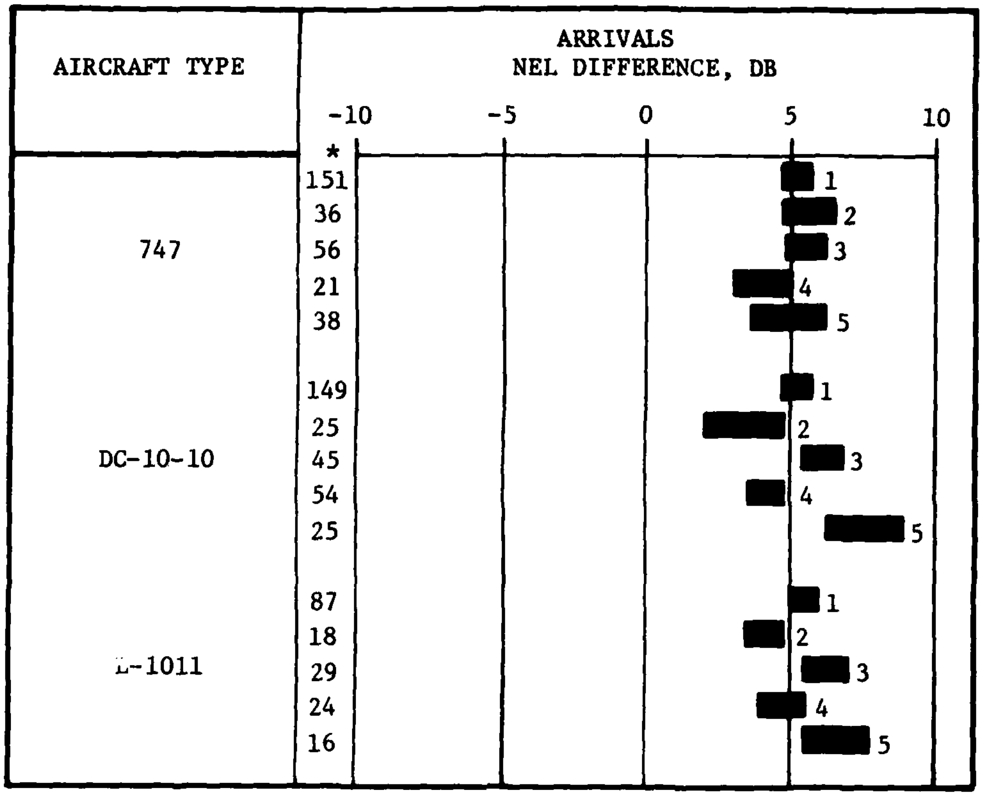


FIGURE 3-16
EMPIRICAL AND INM NOISE CURVES
FOR WIDE BODY DEPARTURES



DATES: 3 MAY 78 - 8 NOV 78

LEGEND:
1 ALL DULLES SITES
2 DULLES NORTH
3 CHANTILLY
4 ARCOLA
5 CENTERVILLE

* SAMPLE SIZE

FIGURE 3-17
DIFFERENCES BETWEEN OBSERVED NOISE AND INM CALCULATIONS FOR WIDE BODY ARRIVALS

The calculated thrusts for wide body arriva's resulting from the noise-thrust mapping procedure are shown in Figure 3-18. All the calculated thrusts exceed the arrival thrust profile for their respective aircraft.

Empirical and INM noise curves for wide body arrivals are shown in Figure 3-19. Comparable NEL curves and confidence regions about them were computed for the DC-10-10 and L-1011, but not for the 747. The DC-10-10 INM curve is up to 11 dB lower than the empirical curve graphed using the median CPA altitude. The L-1011 INM curve is 2 to 5 dB lower than the empirical curve graphed using the median of $\log_{10}$ (CPA elevation angle). Interpretation of these two graphs is difficult because of the necessity finding a simplified two-dimensional relationship from a higher dimensional simulataneous relationship. Nevertheless, both graphs would seem to indicate that the INM calculations are too low in these cases.

3.4 Other Issues

3.4.1 Regression Model for Arrival Operations

Noise exposure values measured at the various monitor sites for arrival operations are statistically less well-behaved than those for departures. As shown by the example of DC-9 arrivals in Figure 2-3, there is considerable variation in the noise exposure level, even for constant distance between the monitor site and the aircraft at the closest point of approach (CPA). For a constant CPA distance, the noise value, in many cases, have a range of over 10 decibels.

Table 3-1 shows the variables selected for use in the regression models used to mathematically describe the observed noise. Traditional modeling techniques use the log of CPA distance as the most significant variable. The regression technique supported this approach for departures (Section 2.3.2). In most of the cases for arrivals, however, the CPA altitude was selected first as the most significant. In only three cases, was the log of CPA distance selected first. The correlation coefficients for the arrivals are nearly in the same range as those for departures, from .82 to .93.

A possible explanation of the appearance of altitude in the regression model for arrivals is that altitude reflects the drag configuration of the aircraft on approach. As the aircraft gets lower in altitude on approach, more drag (in the form of extended landing gear and flaps) is being added, and in order to maintain the same rate of descent and velocity, more thrust is used resulting in more observed noise.

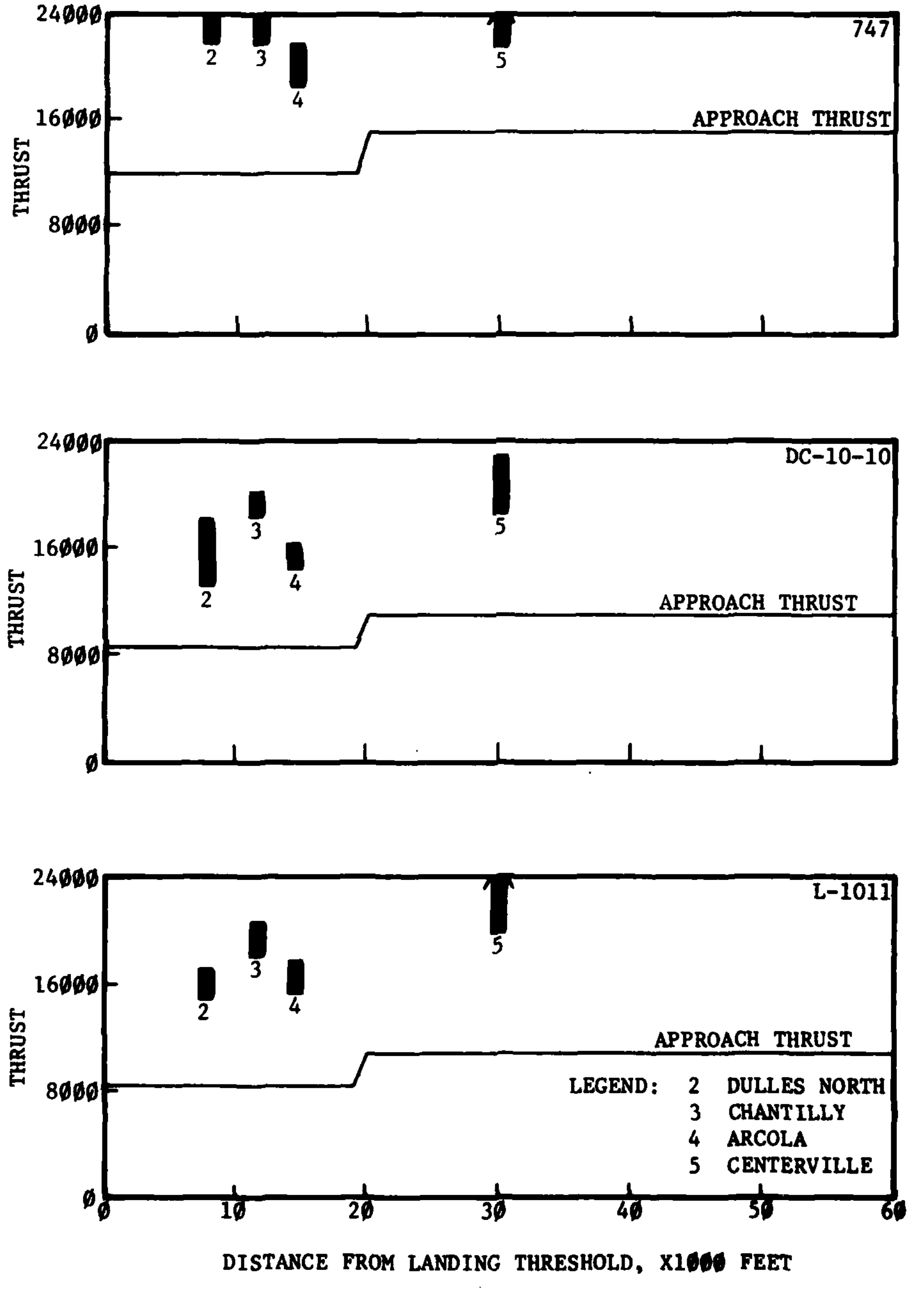


FIGURE 3-18
CALCULATED THRUST FOR WIDE BODY ARRIVALS

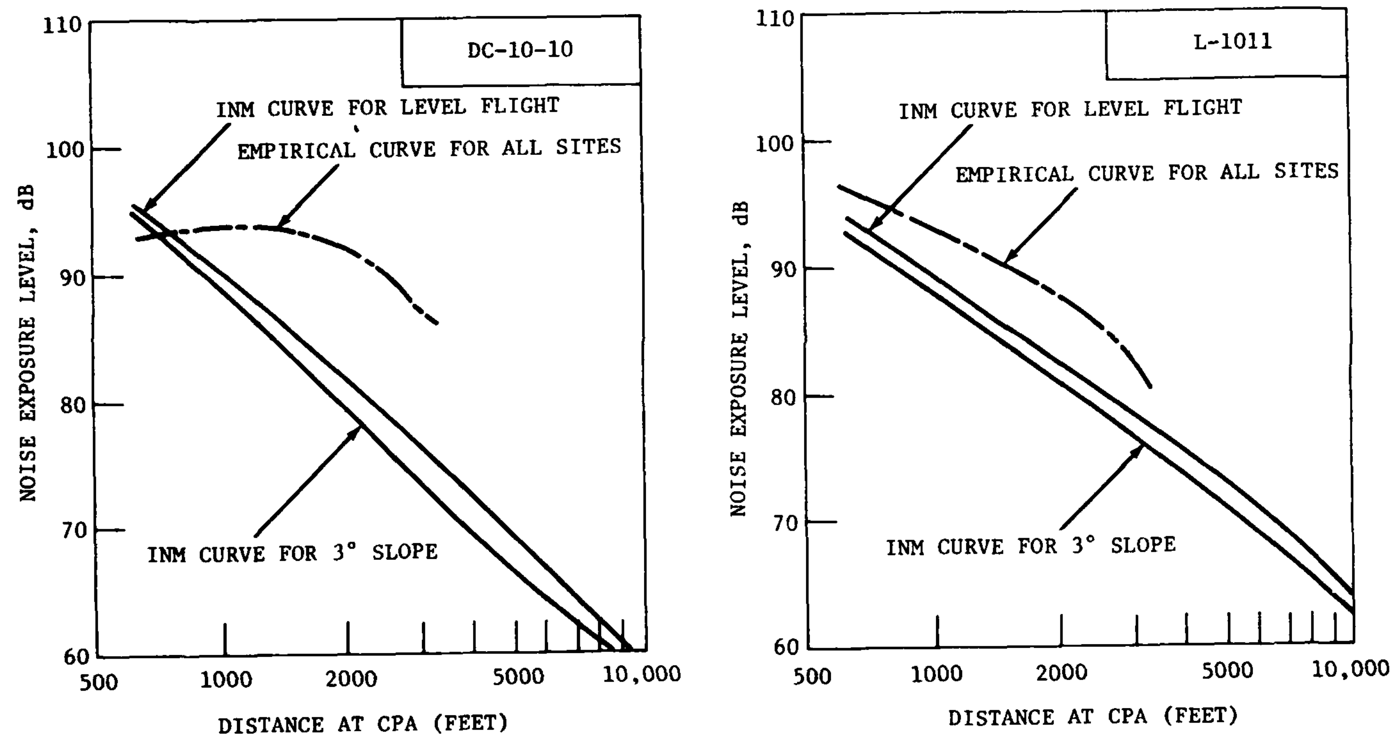


FIGURE 3-19
EMPIRICAL AND INM NOISE CURVES
FOR WIDE BODY ARRIVALS

TABLE 3-1

VARIABLES SELECTED FOR USE IN REGRESSION MODELS FOR OBSERVED NOISE (DULLES)

OPERATION	AIRCRAFT TYPE	VARIABLE NAME							CORRELATION COEFFICIENT
		LOG OF DISTANCE	DISTANCE	ALTITUDE	VELOCITY	LOG OF VELOCITY	VERTICAL VELOCITY	ELEVATION ANGLE	
DEPARTURES	707-120	1	x						.87
	707-320	1	x						.93
	DC-8-55	1						x	.87
	DC-8-60	1							.89
	DC-9	1							.86
	727	1	x				x		.93
	737	1							.81
	747	1						x	.88
	DC-10-10	1							.87
	L-1011	1	x				x		.82
ARRIVALS	707-120			x			1		.82
	707-320			1			x		.90
	DC-8-55	1					x		.82
	DC-8-60			(1)	1		x	x	.91
	DC-9			1	x	x	x		.89
	727	1				x			.84
	737	1					x		.93
	747			1		x			.92
	DC-10-10		x	1					.91
	L-1011		x	1					.93

NOTE: 1 - FIRST VARIABLE TO BE SELECTED
(1) - VARIABLE WAS SELECTED FIRST THEN LATER REPLACED

3.4.2 Comparison of Dulles and National Data

A question arises concerning the degree to which the data sets from Dulles and National airports support similar conclusions or whether these sets support different conclusions. The following addresses the inter-airport results of the comparison of empirical noise curves with those in the INM data base.

For DC-9s, the Dulles empirical curve for Centreville is almost identical to the INM deep cutback curve. The National empirical cutback curve is within the confidence band about the Dulles curve for Centreville. For the DC-9 takeoffs, the two empirical curves are of the same basic shape but have slightly different slopes. The National curve is close to but outside of the confidence region about the Dulles curve, except for CPA distances of 2000-3000 feet where the two curves agree.

For 727s, the Dulles empirical curve for Centreville is in very close agreement with the National empirical curve. Both of these empirical curves are in very close agreement with the INM cutback curve.

For the 737s, there are substantial differences in the curves. However, the sample sizes were also substantially different, the Dulles sample size being 36 while the National sample size was 354.

In summary, the inter-airport results for the computation of empirical noise curves were very consistent, with the exception of the 737 where the two sample sizes were extremely different.

4. CONCLUSIONS

The results of three separate analyses of aircraft departures and arrivals, their noise measurements, and their comparison with analogous noise calculations by the FAA Integrated Noise Model are summarized in Tables 4-1 and 4-2. Based on these results as well as others presented in this study, the following conclusions have been reached concerning the INM's performance in modeling air carrier operations at Dulles International and Washington National Airports.

1. The criterion for "non-agreement" is defined as the average of the paired differences (between actual observed noise from field measurements and calculations of analogous single noise events from the INM) being greater than three decibels (3dB). Using this criterion, noise calculations derived from the use of the INM do not agree with actual observed noise values for four engine narrow body aircraft for departure operations, nor do they agree for most of the wide body aircraft types for departure operations. Because of the wide range of variability in measured values for arrival operations, the interpretation of the arrival data is difficult. (The confidence intervals for the average observed noise differences as well as the confidence band around the regression estimates are large.) Again, using the three decibel criterion for only the observed differences, noise calculations derived from the use of the INM do not agree with actual observed noise values for wide body aircraft for arrival operations.

2. INM calculations of noise events can be changed or calibrated most easily by using two methods: adjusting thrust profiles, and adjusting noise curves. The method of adjusting thrust profiles alone does not have the inherent range (controllability) to allow the calibration necessary to make the results of the INM calculations for four engine narrow body aircraft, for example, comparable to actual measurements (i.e., even when the INM thrust is set for maximum takeoff thrust, the average observed noise is still greater than the resulting INM calculation. This situation is unreasonable since the maximum takeoff thrust is a limiting value, and when set at this maximum thrust value, an aircraft would theoretically produce the loudest possible

possible noise value for that particular aircraft.) In order for the INM calculations to agree with the observed noise, the noise curves in the INM must be adjusted to reflect the actual measurements made in the field by redefining new noise curves.

3. The results of the noise measurements comparisons based data taken at Dulles International Airport are supported by those taken at Washington National Airport for two and three engine narrow body aircraft. (Four engine narrow body aircraft and wide body aircraft operations were observed only at Dulles Airport.)

TABLE 4-1

COMPARISON OF CONTROLLABILITY AND AGREEMENT FOR AIRCRAFT DEPARTURES (NEL OBSERVATIONS)

AIRCRAFT GROUP	AIRCRAFT TYPE	NEL DIFFERENCE BETWEEN OBSERVED NOISE AND INM CALCULATION (dB)[1]	THRUST PROFILES IN INM CAN BE CALIBRATED TO PRODUCE AGREEMENT[2]	AGREEMENT OF 95% CONFIDENCE BAND FOR OBSERVED NOISE WITH INM CLIMB NOISE CURVE[3]	
				AGREEMENT	RELATIVE POSITION
TWO AND THREE ENGINE NARROW BODY	DC-9	-3 to -2	YES	PARTIAL	LOW
	727	-2 to 0	YES	MOST	SLIGHTLY LOW
	737	-3 to -1	YES	PARTIAL	LOW
FOUR ENGINE NARROW BODY	707-120	5 to 6	NO[1]	NONE	HIGH
	707-320	5 to 7	NO	NONE	HIGH
	DC-8-55	2 to 5	NO	PARTIAL	HIGH
	DC-8-60	6 to 7	NO	NONE	HIGH
THREE AND FOUR ENGINE WIDE BODY	747	2 to 3	YES	PARTIAL	HIGH
	DC-10-10	3 to 4	NO	NONE	HIGH
	L-1011	4 to 5	NO	NONE	HIGH

[1]DULLES MONITOR SITES

[2]INM THRUST REQUIRED TO PRODUCE OBSERVED NOISE DURING CLIMB EXCEEDS MAXIMUM THRUST FOR TAKEOFF: INM NOISE CURVES MUST BE REDEFINED TO PRODUCE AGREEMENT

[3]NONE=NO AGREEMENT
PARTIAL=PARTIAL AGREEMENT
MOST=AGREEMENT IN MOST OF RANGE
HIGH=BAND ABOVE INM CURVE
LOW=BAND BELOW INM CURVE

TABLE 4-2

COMPARISON OF AGREEMENT FOR AIRCRAFT ARRIVALS

(NEL OBSERVATIONS)

AIRCRAFT GROUP	AIRCRAFT TYPE	NEL DIFFERENCE BETWEEN OBSERVED NOISE AND INM CALCULATION (dB)[1]	AGREEMENT OF 95% CONFIDENCE BAND FOR OBSERVED NOISE WITH INM APPROACH NOISE CURVES[2]	
			AGREEMENT	RELATIVE POSITION
TWO AND THREE ENGINE NARROW BODY	DC-9	1 to 2	--	--
	727	-3 to -2	PARTIAL	SLIGHTLY HIGH
	737	2 to 4	NONE	HIGH
FOUR ENGINE NARROW BODY	707-120	3 to 4	--	--
	707-320	5 to 6	--	--
	DC-8-55	2 to 4	NONE	HIGH
	DC-8-60	2 to 3	--	--
THREE AND FOUR ENGINE WIDE BODY	747	5 to 6	--	--
	DC-10-10	5 to 6	PARTIAL	HIGH
	L-1101	5 to 6	NONE	HIGH

[1] DULLES MONITOR SITES

[2] NONE = NO AGREEMENT
PARTIAL = PARTIAL AGREEMENT
MOST = AGREEMENT IN MOST OF RANGE
HIGH = BAND ABOVE INM CURVE
LOW = BAND BELOW INM CURVE
-- = NO STATISTICALLY VALID CURVE FOUND

5. RECOMMENDATIONS

The objective of the FAA Integrated Noise Model is to calculate the noise from aircraft operations in the vicinity of an airport (for an average day of the year in an operational environment).

The Noise Exposure Levels (NELs) used in the INM data base were derived mathematically from maximum sound level measurements with duration corrections obtained from Effective Perceived Noise Level (EPNL) measurements by a mathematical method, and thus the NELs in the data base are in part theoretical. From these theoretical values, the noise versus distance curves now residing in the data base were obtained.

On the other hand, the empirical noise versus distance curves presented in this report are a reflection of an actual day of the year in an actual operational environment. These curves were derived from a cross-section sampling of aircraft operations for eight months of data acquisition. The observations are consistent and present a good means to satisfy the stated objective through fine-tuning the INM.

The following steps are recommended in order to improve the accuracy of the INM for aircraft types whose observed noise values do not agree with analogous INM calculations:

1. Adjust the noise curves in the INM for agreement by using empirical noise curves resulting from regression analyses of observed noise values. The noise curves should be adjusted to improve accuracy of noise calculations for takeoff and climb flight operations only, since the actual thrust values used for these operations are procedurally set to a relatively known and fixed value.

2. After adjustment of the noise curves, the noise-thrust mapping procedure described in this study should be used to fine tune or calibrate the thrust profiles for arrival operations. Certain assumptions will have to be made concerning what actual thrust value is being used abeam the various sites, as well as assumptions concerning the flight configuration (i.e., flap and gear extension). These assumptions are an integral part of the calibration process.

3. To insure that the calibration procedure is correct, a complete set of noise observations should be taken at two other airports and the statistical comparisons of observed noise versus INM calculations be repeated.

APPENDIX A

INM NOISE EXPOSURE CALCULATIONS

The determination of the noise exposure calculated by the Integrated Noise Model (INM) as paired to an actual noise event can be broken down into five major sections: (1) correlation of the noise event with radar track and flight plan data, (2) calculation of the closest point of approach (CPA), (3) estimation of the thrust used by the INM under similar flight conditions, (4) determination of the noise versus distance curves for the aircraft type, and (5) calculation of the noise value and with corrections for the flight condition. The methodology for this process is diagrammed in Figure A-1.

A.1 Calculation of Closest Point of Approach

The closest point of approach (CPA) for an aircraft as it passes near a monitor site is a result of using an second order regression estimate of the flight's radar track history. The ARTS III radar track histories for an aircraft flyby consists of a series of position reports P_n, where n is the number of the beacon report for a particular track. The following text contains a mathematical description of the method used to obtain an estimate for the CPA for these position reports.

P_n can be written parametrically as

$$P_n = (x_n, y_n, z_n, t_n)$$

where

> (x_n, y_n) is the abscissa and ordinate respectively of the aircraft's position
>
> z_n is the altitude of the aircraft
>
> t_n is the time at which the position report occurred.

Because of the quantization characteristic of the ARTS III system, the altitude values are rounded to the nearest 100 feet. The time between position reports $(t_{n+1}-t_n)$ is approximately four seconds.

The raw data estimate for the CPA is found by calculating the minimum distance from all the position reports ranging over the [illegible]

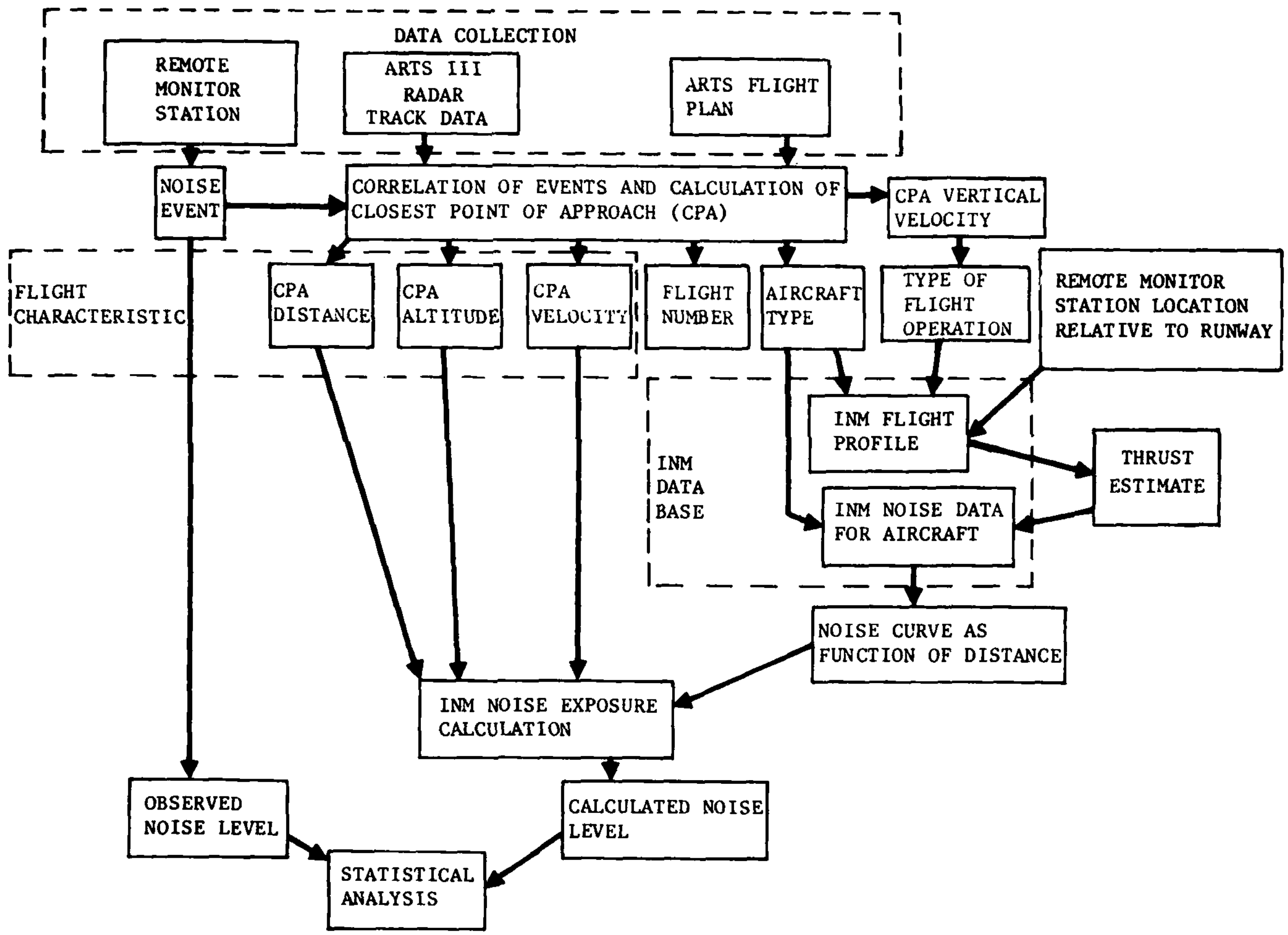


FIGURE A-1
VALIDATION METHODOLOGY

$$P_n^* = \underset{i}{\text{minimum}} \left[\sqrt{x_i^2 + y_i^2 + z_i^2} \right] \quad \text{for } P_i$$

The five reports preceeding and following this report p_n^* are then selected for the second order regression estimates. To obtain estimates of the CPA, using the position reports P_{n-5}, P_{n-4}, ..., P_n^*, ..., P_{n+5}, three least squares regressions were performed by x versus t, y versus t, and z versus t.

The resulting form of the least squares regressions using orthogonal polynomials is:

$$x = \frac{1}{2} A_x t^2 + V_x t + X_x$$

$$y = \frac{1}{2} A_y t^2 + V_y t + X_y$$

$$z = \frac{1}{2} A_z t^2 + V_z t + X_z$$

where A, V, and X are constants representing acceleration, velocity and initial position respectively.

Using the parametric estimates for x, y, and z, the actual CPA is found by numerically computing the minimum distance for the range t_{n-5} to t_{n+5} by incrementing time in the parametric estimates by .1 seconds. The time at CPA is t^*.

$$CPA = \underset{t_k}{\text{minimum}} \left[\sqrt{x_{t_k}^2 + y_{t_k}^2 + z_{t_k}^2} \right] \text{for} \begin{cases} t_{n-5} \le t_k \le t_{n+5} \\ t_k = t_{k-1} + .1 \end{cases}$$

t^* = value of t_k which yields CPA

The velocity estimate at CPA is

$$V^* = \sqrt{\dot{x}^2 + \dot{y}^2} \quad \text{for } t^*$$

where x and y are first derivatives of the regression estimates. The vertical velocity at CPA is the first derivative of the altitude regression estimate z for t^*.

A.4 Estimation of Thrust and Determination of Noise Versus Distance Curves

The Integrated Noise Model has a number of aircraft definitions stored in its data base, as listed in Table A-1. Those aircraft which have been checked are those which have been used for comparison purposes in this analysis. The aircraft definitions consist of flight profiles, noise versus distance curves, and other parameters used in calculating noise values for a particular aircraft.

TABLE A-1

AIRCRAFT DEFINITIONS STORED IN THE INM

AIRCRAFT NAME	
2E NBTF	DC-9-32
	DC-9-15
	BAC-111
	737/100-200
3E NBTF	727-200
	727-100
4E NBTF	707-320B/C
	707-120B
	720B
	DC-8-55
	DC-8-61/63
	Convair-990
4E NTJ	707-120/320
	720
	DC-8-30
	Convair-880
	VC-10
STOL	F-28-2000
SST CONCORDE	
2 Engine Wide Body	
3E MRWB	DC-10-10
3 Eng. WB	L-1011
3E LRWB	DC-10-30
3E LRWB	stretch
4 Eng. WB	747-200
	747-100
	747- stretch
DC9 w/SAM Engines	
737 w/SAM Engines	
727 w/SAM Engines	
707 w/SAM Engines	
DC w/SAM Engines	
727 Adv. w/SAM Engines	
727 Adv. w/RFN Engines	
2ETFGA SABRELINER	
2ETP TWIN OTTER	
2EP CESSNA 310	

The INM uses a flight profile table relating distance along track, altitude, velocity, and thrust in conjunction with a ground track definition to determine an aircraft's flight conditions for a given point along the track. Flight profiles are broken up into linear segments as shown in Figure A-2. Figure A-2 shows parametric relationship between altitude, velocity and thrust as a function of distance from start of takeoff roll or landing threshold. In this study, however, only the thrust profile is used to estimate the thrust abeam a monitor site. The measured altitude and velocity from the radar data are used in the INM calculation. Once the thrust value abeam the site is estimated, then the noise versus distance curve for that thrust setting can be obtained from the INM data base. An example of noise curves for 727 aircraft is shown in Figure A-3.

A.5 Calculation of Noise Values

The noise curve for a particular aircraft type together with its measured flight characteristics are used to calculate the noise level for a flyover. This process is outlined in Figure A-4 and more fully explained in Reference 1.

The noise curve and CPA distance are used to interpolate in the noise curve for the uncorrected value for the noise level. The CPA velocity is used to compute a velocity correction. For NEL values, additional corrections are made, using the CPA altitude for shielding and excess ground attenuation factors.

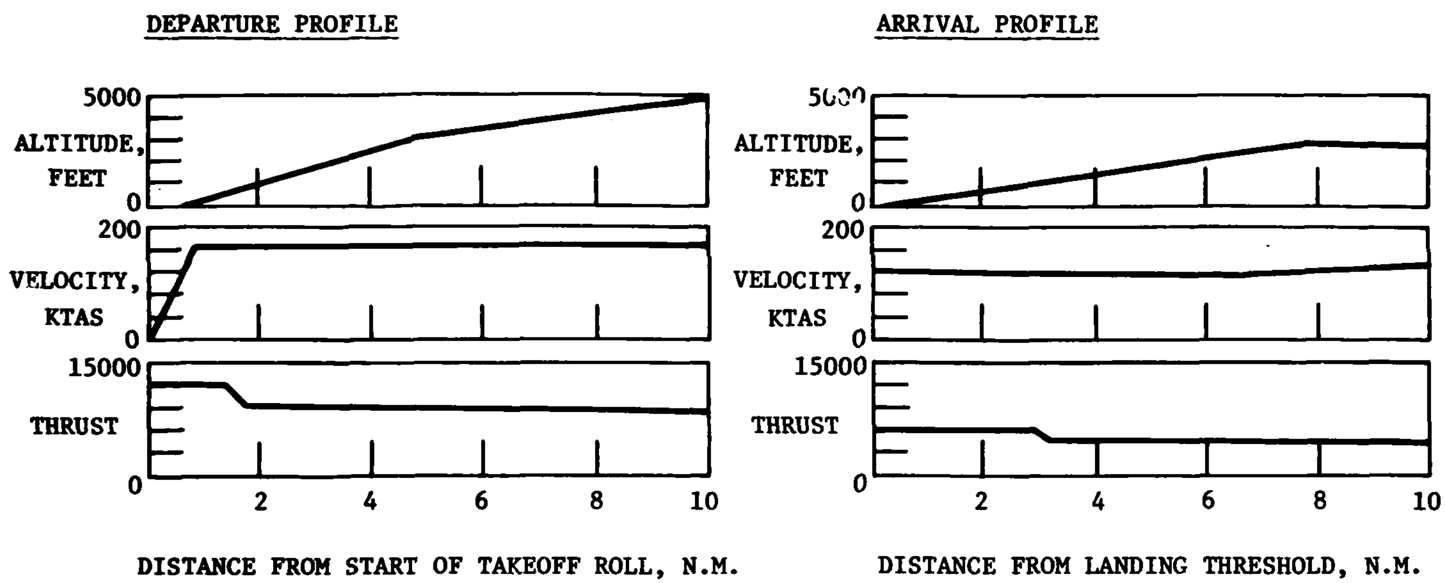


FIGURE A-2
EXAMPLE OF 727 FLIGHT PROFILES

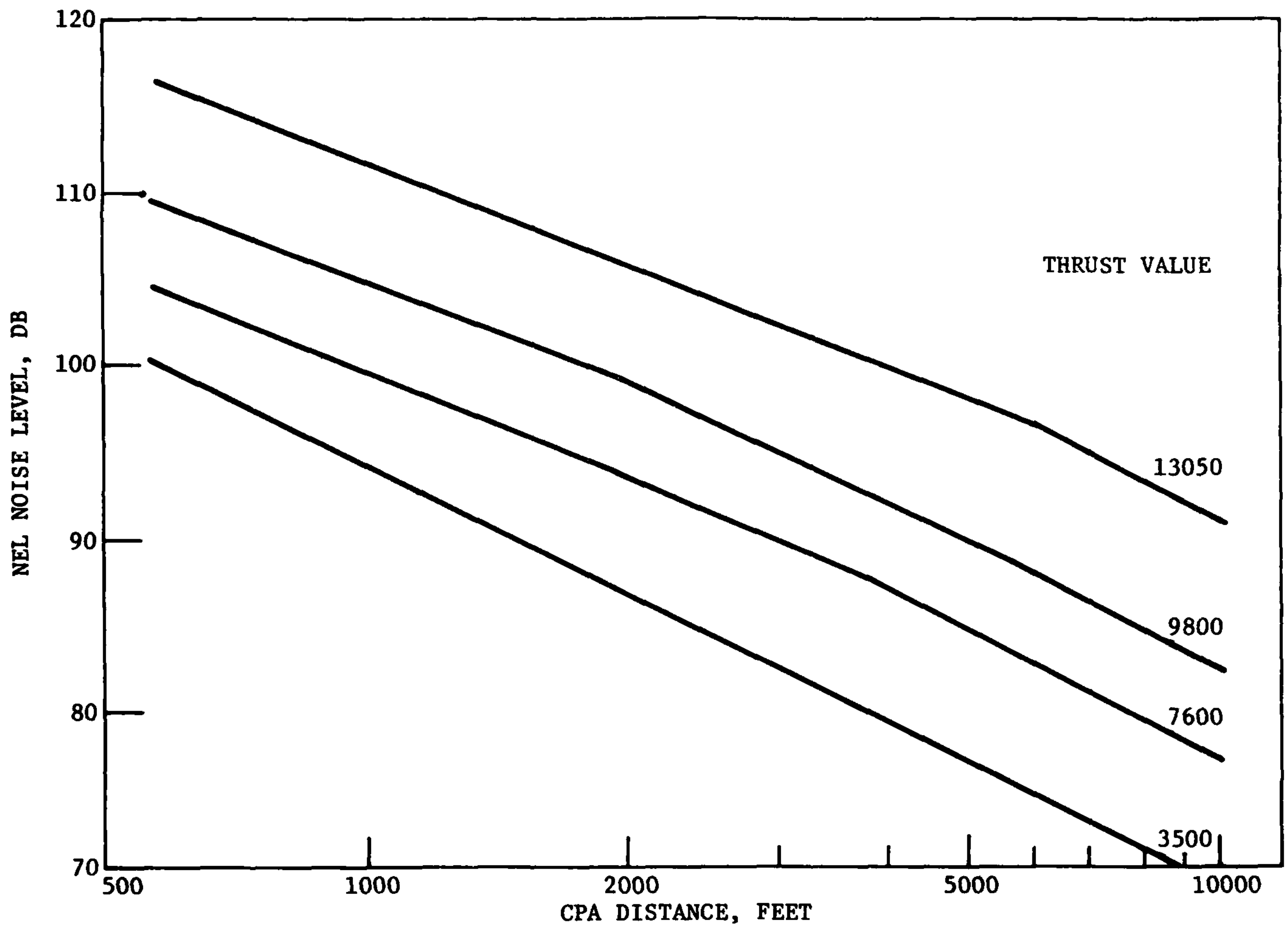


FIGURE A-3
EXAMPLE OF 727 NOISE CURVE DATA
FOR INM DATA BASE

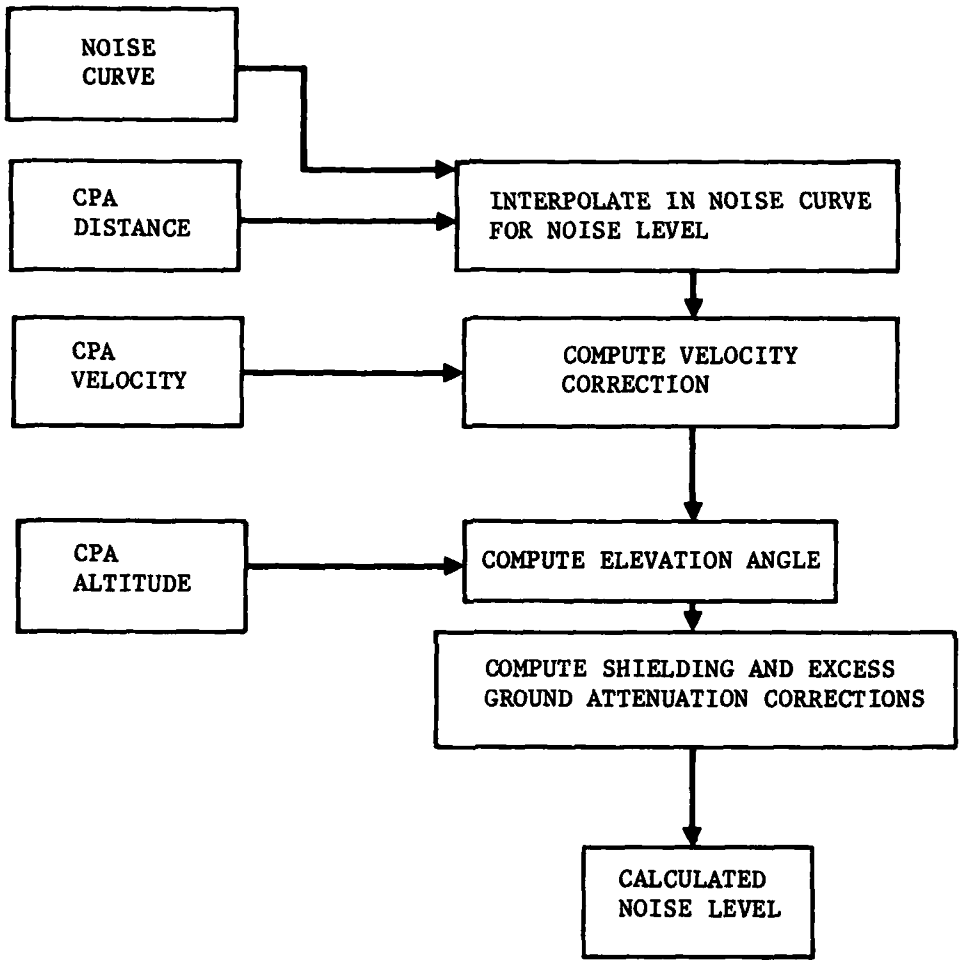


FIGURE A-4
INM NOISE EXPOSURE CALCULATION

APPENDIX B

STATISTICAL TOPICS FOR REGRESSION ANALYSIS

The following sections discuss the statistical foundations of the computation of empirical noise curves and their comparison with the INM curves.

B.1 Indicator Variables

An indicator variable is used to indicate whether each individual observation in the data possesses a certain characteristic of interest. The indicator variables in these analyses were set equal to 1 when the characteristic in question was possessed by the observation and equal to 0 otherwise. For departures, the variable "climb" was included to indicate whether the CPA altitude was above 1500 feet, because of the changes in thrust dictated by takeoff procedures at this point. Indicator variables were also used for monitor site and airline. When a characteristic, such as airline, has several subdivisions, it is customary to use one fewer indicator variable than there are subdivisions, because of the mathematical properties of the regression calculations (Reference 4).

Thus for the 707-320 departures observed at four Dulles Airport sites, three indicator variables for site were included, one each for Dulles North, Chantilly, and Centreville. A general list of the variables tested in each case is given in Table B-1.

Notice that when an indicator variable is significant, its effect is to add the value of its coefficient to the constant of the regression equation for those observations having the indicated characteristic. Thus, since the empirical NEL curve for the 707-320 departures at Dulles Airport is

$$\text{NEL} = 153.864 - 7.267 * \text{CENTREVILLE} - 14.397 * \text{LOG}_{10}\ (\text{CPA DISTANCE}) - 0.002 * \text{CPA DISTANCE},$$

this "curve" is really two different curves as follows:

1. For observations at Dulles North, Chantilly, and Arcola,
   $$\text{NEL} = 153.864 - 14.397 * \text{LOG}_{10}\ (\text{CPA DISTANCE}) - 0.002 * \text{CPA DISTANCE}.$$

2. For observations at Centreville,
   $$\text{NEL} = 146.597 - 14.397 * \text{LOG}_{10}\ (\text{CPA DISTANCE}) - 0.002 * \text{CPA DISTANCE}.$$

TABLE B-1

VARIABLES TESTED FOR SIGNIFICANCE

TYPE	VARIABLES
INDICATOR	MONITOR SITES AIRLINES CLIMB
QUANTITATIVE	CPA RANGE CPA ALTITUDE CPA VELOCITY CPA VERTICAL VELOCITY CPA ELEVATION ANGLE
TRANSFORMATIONS	LOG_{10} (CPA DISTANCE) LOG_{10} (CPA ALTITUDE) LOG_{10} (CPA ELEVATION ANGLE)

In such cases, the curve indicating lower noise levels at sites farther from the runway is comparable to an INM curve for thrust reduced appropriately below takeoff power.

B.2 Stepwise Regression

When a stepwise procedure is used, the principle of parsimony should be applied in deciding which model to select. In other words, one should weigh the merits of having the best least squares fit possible against the merits of having a model with few independent variables, which is thus easily used and interpreted. Thus, it may be wiser to choose a model with a lower correlation coefficient but with fewer variables. For example, if a seven-variable model were chosen from the stepwise procedure, the last several variables to enter the model might reflect relationships specific to the input data rather than relationships with the desired general application. Hence, the empirical NEL curves used for comparison were judiciously chosen in an attempt to have an easily interpretable model with a good least squares fit.

Once an empirical noise curve was selected, the statistical assumptions that every regression model must satisfy were examined (Reference 7).

As an example, the stepwise procedure for the 707-320 departures at Dulles Airport is illustrated in Table B-2. Notice that those variables which are thought to be fundamental in estimating noise levels are put into the model in the first few steps and result in a good least squares fit as measured by the multiple correlation coefficient (R).

The stepwise regression procedure is an economical way of computing a set of "best" independent variables to use in estimating a dependent variable. Initially, each possible simple linear regression is computed along with its corresponding F* statistic for testing whether the coefficient of that independent variable in zero. Here

$$F^* = \frac{\Sigma(\hat{Y}_i - \bar{Y})^2/(p-1)}{\Sigma(Y_i - \hat{Y}_i)^2/(n-p)}$$

where n is the sample size, (p-1) is the number of independent variables in the model, Y is the dependent variable, and the $\hat{Y}_i$'s are the values of Y estimated by the regression function (the "fitted" values). The independent variable which results

TABLE B-2

STEPWISE CALCULATIONS FOR EMPIRICAL NEL CURVES -
707-320 DEPARTURES AT DULLES AIRPORT

STEP NO.	CONSTANT	INDEPENDENT VARIABLES							R	R^2	INCREASE IN R^2
		LOG_{10}(DIST)	CENTERVILLE*	DISTANCE	PA*	EL ANG	AA*	LOG_{10}(EL ANG)			
1	202.392	-30.503							.8826	.7790	.7790
2	191.652	-27.076	-6.975						.9275	.8603	.0813
+3	153.864	-14.397	-7.267	-0.002					.9332	.8709	.0106
4	148.140	-12.345	-7.232	-0.002	-1.714				.9380	.8799	.0090
5	158.240	-14.648	-6.720	-0.002	-1.746	-0.040			.9415	.8865	.0066
6	154.854	-13.403	-6.934	-0.002	-2.145	-0.042	-1.197		.9433	.8899	.0034
7	155.291	-11.744	-6.909	-0.003	-2.168		-1.336	-4.428	.9437	.8905	.0006

NOTE: SAMPLE SIZE = 166

\+ MODEL SELECTED

* INDICATOR VARIABLES
PA = PAN AMERICAN AIRLINES
AA = AMERICAN AIRLINES

in the largest F* value is added to the model. The correlation coefficient (R) between the observed values and the fitted values of the dependent variable for any regression model is computed as follows:

$$R = \frac{(\hat{Y}_i - \bar{Y})^2}{(Y_i - \bar{Y})^2}$$

On each successive step of the stepwise procedure, the model is examined to determine whether the R value can be increased by interchanging one variable in the model with one variable not in the model. If an interchange is not beneficial, the variable with the largest F* value, computed in a manner analogous to that shown earlier, is added to the model.

The procedure terminates when the largest F* of variables not in the model is below some predetermined level, indicating that any other variables added to the model would have coefficients equal to zero. The predetermined cutoff for F* has no exact probabilistic interpretation because of the iterative nature of the process. However, a cutoff of F(.95,1,n) was used in general to roughly correspond to a single test of this nature.

B.3 Computation of a Confidence Region about a Regression Curve

The confidence regions for the empirical NEL curves were computed using an extension of the Working-Hotelling confidence bands for a regression line with only one independent variable. At each of 25 points on the curve, chosen somewhat uniformly throughout the range of the CPA distance for that data, a 95% confidence interval about that point was computed as follows: For a particular level of the (p-1) independent variables X_h, the vector of regression coefficients B, and the data matrix X, the interval about $X_h{}'B$, the value of the curve is

$$\hat{Y}_h - W\, s(\hat{Y}_h) \le X_h' B \le \hat{Y}_h + W\, s(\hat{Y}_h)$$

Where $s^2(\hat{Y}_h)$ = MSE $(X_h'(X'X)^{-1}X_h)$ for MSE = the mean square error of the regression and $W^2 = P\ F(.95;p,n-p)$.

Notice that the width of the confidence region is proportional to the value of $F(.95;p,n-p)$. Therefore, if the confidence level were decreased to say 80% rather than 95%, the width of the confidence region would decrease since $F(.80;p,n-p)$ $F(.95;p,n-p)$.

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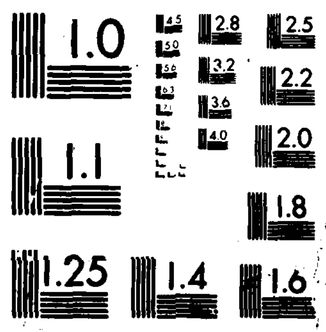

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX C

EMPIRICAL NOISE CURVES FROM REGRESSION ANALYSIS

The following tables provide a case by case comparison of the equations of the empirical noise curves resulting from the regression analyses described in Appendix B.

THE EQUATIONS OF THE EMPIRICAL NEL CURVES

TABLE C-1

FOUR ENGINE NARROW BODY DEPARTURES (DULLES)

AIRCRAFT TYPE	SAMPLE SIZE	RANGE OF CPA DISTANCE	CONSTANT	INDEPENDENT VARIABLES				R^2
				CPA DISTANCE	$\text{LOG}_{10}\left(\text{CPA DIST}\right)$	CENTER-VILLE	ELEVATION ANGLE	
707-120	51	1201-9997	223.138	0.002	-38.600	-3.039		.75
707-320	166	914-8650	153.855	-0.002	-14.394	-7.266		.87
DC-8-55	32	940-9754	208.584		-31.107		-0.091	.76
DC-8-60	184	877-7762	172.177		-21.304	-4.996		.79

TABLE C-2

FOUR ENGINE NARROW BODY ARRIVALS (DULLES)

AIRCRAFT TYPE	SAMPLE SIZE	RANGE OF CPA DISTANCE	CONSTANT	INDEPENDENT VARIABLES								R^2
				$\text{LOG}_{10}\left(\text{CPA DIST}\right)$	CENTER-VILLE	ELEVATION ANGLE	CPA ALTITUDE	CPA VELOCITY	VERTICAL VELOCITY	TWA	AA	
707-120	182	604-5918	119.534				-0.011		0.007	-2.928	-4.816	.67
707-320	202	623-6510	117.437		-3.703		-0.011		0.007			.82
DC-8-55	38	639-3060	178.057	-23.845					0.006			.68
DC-9-60	166	685-3438	125.651		-13.854	-0.128		-0.091	0.004			.83

TABLE C-3

TWO/THREE ENGINE NARROW BODY DEPARTURES (DULLES AND NATIONAL)

AIRCRAFT TYPE	SAMPLE SIZE	RANGE OF CPA DIST	CONSTANT	INDEPENDENT VARIABLES							R^2
				CPA DISTANCE	$LOG_{10}\left(\begin{matrix}CPA\\DIST\end{matrix}\right)$	CENTER-VILLE	CPA VELOCITY	VERTICAL VELOCITY	$LOG_{10}\left(\begin{matrix}EL\\ANG\end{matrix}\right)$	OLD TOWN	
DC-9	301	961-8316	162.330		-19.754	-4.535					.74
727	292	1048-9556	148.373	-0.001	-14.272	-3.742		0.001			.87
737	36	1179-6506	159.063		-19.270						.66
DC-9*	326	1560-9738	135.362		-14.696			0.002		6.870	.70
727*	344	1522-8985	187.897		-24.669		-0.072	-0.003			.63
737*	354	1908-9183	94.678		- 6.377				7.502	9.291	.70
BAC-111*	277	2073-9901	90.312	-0.002				-0.004		5.597	.72

*NATIONAL SITES

TABLE C-4

TWO/THREE ENGINE NARROW BODY ARRIVALS (DULLES AND NATIONAL)

AIRCRAFT TYPE	SAMPLE SIZE	RANGE OF CPA DISTANCE	CONSTANT	INDEPENDENT VARIABLES					R^2
				$LOG_{10}\left(\frac{CPA}{DIST}\right)$	CENTER-VILLE	CPA ALTITUDE	VERTICAL VELOCITY	LOG_{10}(VELOCITY)	
DC-9	311	602-6302	144.486		-7.253	-0.6004	-0.002	-19.711	.80
727	465	603-6301	208.449	-17.245				-28.678	.71
737	30	624-3087	173.127	-23.753			-0.007		.86
DC-9*	356	1334-9681	NO VALID MODEL COULD BE FOUND.						-
727*	411	1189-9584	NO VALID MODEL COULD BE FOUND.						-
737	205	1122-7774	NO VALID MODEL COULD BE FOUND.						-
BAC-111*	169	1319-7445	NO VALID MODEL COULD BE FOUND.						-

*NATIONAL SITES

TABLE C-5

THREE/FOUR WIDE BODY DEPARTURES (DULLES)

AIRCRAFT TYPE	SAMPLE SIZE	RANGE OF CPA DIST	CONSTANT	INDEPENDENT VARIABLES					R^2
				CPA DISTANCE	LOG_{10} (CPA DIST)	CENTER-VILLE	ELEVATION ANGLE	VERTICAL VELOCITY	
747	92	795-7307	196.516		-28.673		-0.079		.77
DC-10-10	90	1168-5159	155.911		-19.061	-4.134			.76
L-1011	85	1065-9529	202.412	0.003	-32.912			-0.003	.68

TABLE C-6

THREE/FOUR ENGINE WIDE BODY ARRIVALS (DULLES)

AIRCRAFT TYPE	SAMPLE SIZE	RANGE OF CPA DISTANCE	CONSTANT	INDEPENDENT VARIABLES					R^2
				CPA DISTANCE	LOG_{10} (CPA DIST)	CPA ALTITUDE	LOG_{10} (CPA VELOCITY)	LOG_{10} (ELEVATION ANGLE)	
747	100	615-6197	180.460			-0.013	-33.285		.85
DC-10-10	118	619-3246	54.979	-0.007	17.833	-0.009			.83
L-1011	75	609-3410	118.289	-0.006				-10.499	.86

APPENDIX D

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APPENDIX E

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APPENDIX -

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